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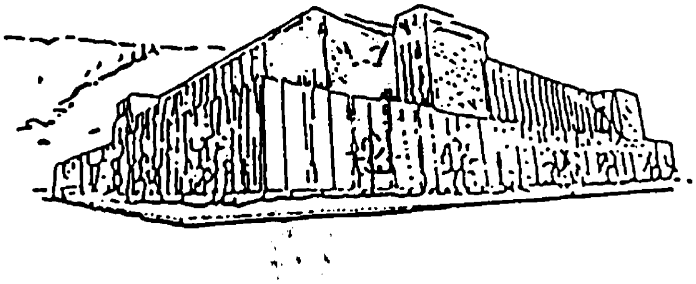

DEFINING BENEFIT AND HAZARD: DISTRIBUTION OF UPPER AND LOWER TERTIARY UNITS ON THE NORTHEAST FLANK OF THE MISSOULA VALLEY, MONTANA

by

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ABSTRACT

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Defining Benefit and Hazard: Distribution of Upper and Lower Tertiary Units on the Northeast Flank of the Missoula Valley, Montana

Director: James W. Sears

Two Tertiary units on the northeast flank of the Missoula Valley are distinct from each other; the lower unit bears resemblance to the middle Eocene to late early Miocene Renova Formation, and the upper unit closely resembles the middle Miocene to Pliocene Sixmile Creek Formation. However, previous studies mapped the two units together or partially differentiated the units in an inconsistent manner. Exposures are limited, and strata are difficult to trace on the valley flank. But the units can be mapped separately. Outcrops of conglomerate containing mylonite clasts indicate the depositional environment of the lower Tertiary unit included a river flowing north from an ancestral Bitterroot Valley. Deposits near the southern end of the valley flank indicate the river was flanked by series of coalescing alluvial fans. Though similar to the Renova Formation, the lower Tertiary unit is distinct because it contains exotic clasts deposited in a fluvial environment.

I identified two lithologic facies of the upper Tertiary unit. A conglomerate facies is in angular unconformable contact with the northeast-dipping lower Tertiary unit. This is a fluvial deposit and may be ancestrally related to the Clark Fork River. A boulder-dominated conglomerate facies of the upper Tertiary unit, coeval with the fluvial deposit, was generated from a broad debris-flow/alluvial fan system which flowed primarily out of an ancestral Grant Creek. A lack of age evidence within the upper Tertiary unit makes its assignment to the Sixmile Creek Formation premature.

The mylonite-bearing, non-lenticular, coarse fluvial deposits of the lower Tertiary unit can transmit significant quantities of water to wells. Based on bedding orientations taken from outcrops, these beds can be targeted in the subsurface.

Landslides on the valley flank result from the interplay of the lower and upper Tertiary units. Interstitial water drains through the coarse upper Tertiary unit and travels along the contact between the upper and lower units. Near the topographic surface, where the water-logged contact intersects with poorly lithified, clayey, ash-rich beds of the lower Tertiary unit, landslide failure may occur if the topography along the contact is sufficiently steep. Overburden from the upper Tertiary unit adds to the driving forces necessary for slippage. A reasonable estimate of landslide potential can be made based on proximity to the geologic contact between the upper and lower Tertiary units.

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1.0 INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

1.1.1 Overview

Tertiary deposits and Quaternary sediments fill Montana's Missoula Valley. The valley is part of a northwest-trending intermontane basin which overlies complexly deformed Cambrian and Precambrian bedrock (McMurtrey et al., 1965; Hall, 1968; Geldon, 1979; Smith 1992). The most extensive occurrence of Tertiary deposits forms the northeast flank of the Missoula Valley and extends into Ninemile Valley to the northwest (McMurtrey, et al., 1965). This study focuses on the southern part of this area, from Rattlesnake Creek on the southeast to O'Keefe Creek on the northwest.

Aside from middle Eocene volcaniclastics and conglomerates, Tertiary sedimentary rocks found within western Montana consist of two distinct deposits separated by an unconformity that is typically angular (Thompson et al., 1981; Fields et al. 1985). In the basins of southwest Montana these strata have been defined as the Renova and Sixmile Creek Formations (Kuenzi and Fields, 1971).

The Renova and Sixmile Creek Formations have been mapped separately in various Montana basins (eg. the Ruby River basin by Monroe, 1976, and Warner, 1996; the Jefferson River basin by Kuenzi and Fields, 1971, and Petkewich, 1972; and the Deer Lodge Valley by McLeod, 1987 and Rasmussen, 1989), but the Tertiary stratigraphy in the Missoula Valley has largely been undifferentiated.

Reconnaissance studies indicated that the Tertiary strata in the Missoula Valley include two units similar to the Renova and Sixmile Creek Formations. These units have either been mapped together as undifferentiated Tertiary deposits (McMurtrey, *et al.*, 1965; Hall, 1968), or have been partially differentiated in an inconsistent manner (Van der Poel, 1979; Whittingham, 1986).

Thus, in the Missoula Valley there was a need to map these two units separately and consistently to elucidate the stratigraphic framework. This project began that process by geologically mapping the largest occurrence of Tertiary deposits in the valley, along its northeast flank.

1.1.2 Aquifer Potential

The Renova Formation has long been considered a fine-grained formation with only minor lenses of coarse clastic deposits (Kuenzi and Fields, 1971; Fields et al., 1985; Rasmussen 1993; Janecke, 1994). Consequently, the Renova Formation is not highly deemed for its aquifer potential. In the Missoula Valley, Woessner (1988) summarized the aquifer potential of "Renova equivalent" rocks on the flanks of the Missoula Valley as yielding "small quantities of water to wells" which support only limited domestic use. Geldon (1979) concluded that the sporadic occurrence of discontinuous layers of water-bearing sand and gravel within the mostly fine-grained "Oligocene-Miocene sediments" make it impossible to predict the depth at which ground water would be encountered.

Since the Tertiary units have not been accurately mapped in the Missoula Valley, their varied lithologies have been simply classified as fine-grained with minor discontinuous lenses of coarser material. Consequently, no real attempt at determining the extent and distribution of coarse-grained deposits within the units has been made, and therefore, the aquifer potential of these deposits has been overlooked.

Preliminary field reconnaissance revealed significantly thick deposits of conglomerate within the lower Tertiary unit. Geologic mapping for this project provides accurate attitude orientations for some of these coarse deposits, and well log records provide correlative subsurface lithologic and groundwater yield information. This project used this information to evaluate the aquifer potential of these coarse layers within a coherent stratigraphic framework.

1.1.3 Landslide Potential

Landslides are known to occur in the Renova Formation (Alt and Hyndman, 1990) and several landslides occur within the Tertiary units on the northeast flank of the Missoula Valley. The determination of where and why a landslide will occur is dependent on lithology, bedding orientation, slope angle, presence of water, overburden, and other factors. As the development pressures of the Missoula Valley have increased, building has encroached onto the flanks of the valley, including the northeast flank. The need has arisen for the evaluation of landslide potential. But because the distribution and orientation of Tertiary deposits have not been accurately determined, and because landslides on previously undeveloped land have not been a concern, landslide potential on the northeast flank of the Missoula Valley has been overlooked. This project presents an overview of landslide potential based on observations of an active landslide on the valley flank and correlation with other landslides mapped within the field area.

1.2 SCOPE

This project has had several objectives. First I isolated the occurrence of Tertiary deposits within the field area by mapping the contacts between the Tertiary and preTertiary and the Tertiary and Quaternary units. Second, I measured and characterized the Tertiary stratigraphy of the Tertiary deposits based on limited exposures. In the field area, grading operations at the Browning Ferris Industries (BFI) landfill have exposed a succession of Tertiary strata that is nearly 200 meters thick. I compiled stratigraphy here to provide a basis for geologic mapping of the units. Smaller exposures in the field area provided additional stratigraphy. Third, I mapped the two Tertiary units along the northeast flank of the Missoula Valley. The two Tertiary units were mapped separately. Two facies of the younger unit have been mapped: conglomerate and boulder-dominated conglomerate. Very limited exposure of the older unit necessitated the search for outcrops created by roadcuts, grading of building pads, gravel pits and other excavations, and stream erosion. I noted the lithology at each exposure so that significant lithologic changes could be traced over the field area and possible facies changes within the unit could be observed. Fourth, I scrutinized well logs from wells drilled in the down-dip vicinity of coarse clastic deposits within the older unit in an attempt to assess the aquifer potential of the coarse-grained strata. Fifth, I assessed landslide potential on the northeast flank of the Missoula Valley based on evaluation of landslides mapped within the field area. Sixth and finally, in the process of meeting the above objectives, I developed a depositional interpretation for the two Tertiary units in the Missoula Valley.

1.2.1 Cited Locations

I used the United States Bureau of Land Management system of land subdivision as a means for locating on the geologic map (Plate 1) various features discussed in the text. This method is graphically explained in Figure 1.

1.3 METHODS OF STUDY

During the summer of 1996, I measured stratigraphic sections of the Tertiary deposits at the BFI landfill, north of Missoula. Grading operations at the landfill created two adjoining excavation sidewalls. Nine stratigraphic columns were compiled along the sidewalls to illustrate the thickness and lateral extent of the beds exposed. Grading operations north of the excavation sidewalls further exposed Tertiary deposits; two additional columns were measured from this exposure. Smaller stratigraphic compilations were made from exposures near Butler Creek and US Route 93 (US93). The stratigraphic columns were compiled using a Jacob's staff and an inclinometer.

The surface geology was mapped on US Geological Survey (USGS), 7-1/2 minute quadrangle maps of the Northeast and Northwest Missoula quadrangles, scale 1:24,000, during the summer and fall of 1996. The data was then transferred to a computer-aided-drafting (CAD) version of the quadrangle maps using the CAD software Microstation. This was performed for graphics purposes, but primarily the geology was converted to a computer format so that a disk copy of the map could be amended with additional geologic information. Excavations related to road building and construction in the field

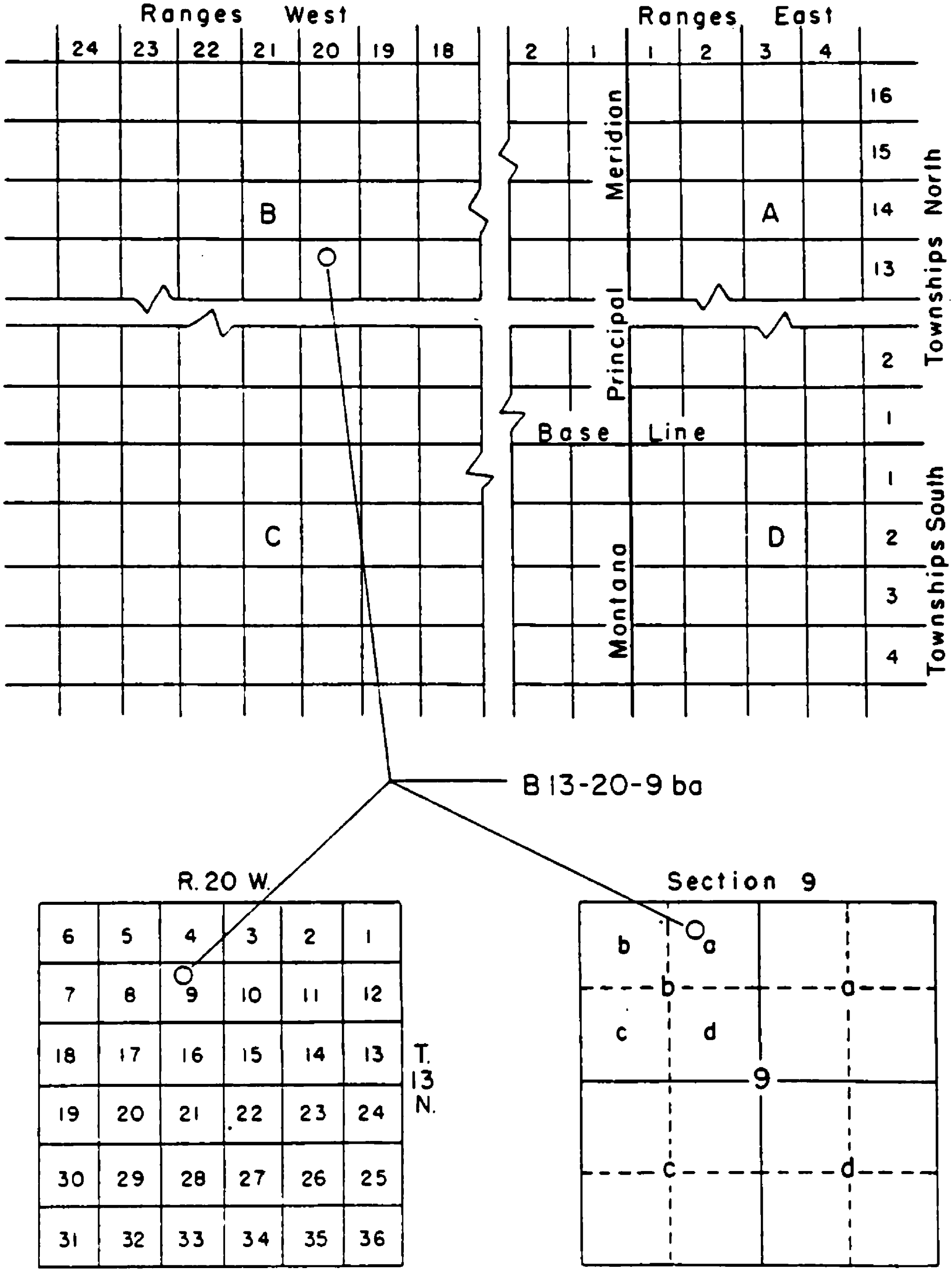

Figure 1: United States Bureau of Land Management location method

area will continue, creating good, but temporary exposures of Tertiary deposits. The disk copy of the map can be updated when these new exposures are made. Well logs were obtained from the Butte office of the Montana Bureau of Mines and Geology (MBMG) and from MBMG open-file report 46 (Norbeck, 1980), which evaluated deep aquifers in the Missoula and Bitterroot Valleys. Stratigraphy from select wells was correlated with mapped outcrops based on bedding geometry.

Landslide potential was evaluated based on field observation of an active landslide near the mouth of Grant Creek. Components of the active slide, including head scarp, failure surface, and toe have been exposed due to its movement in 1996, enabling both surface and subsurface observation. Features of inactive landslides mapped in the field area, such as lithology and slope angle, are compared with the active slide, allowing for a general measure of landslide potential.

1.4 PHYSIOGRAPHY

The intermontane basin which includes the Missoula Valley is within west-central Montana. It extends northwest from the city of Missoula approximately 80 kilometers (km) into Ninemile Valley (Figure 2). The basin is approximately eight miles wide at its southern end and pinches toward the head of Ninemile Valley. The Missoula Valley fits within the southern half of the basin and is delineated by the Clark Fork River which drains to the northwest. Ninemile Creek drains the Ninemile Valley, the northern half of the basin, and flows southeast to its confluence with the Clark Fork River. The Bitterroot River, flowing north from the Bitterroot Valley, flows into the south end of the Missoula

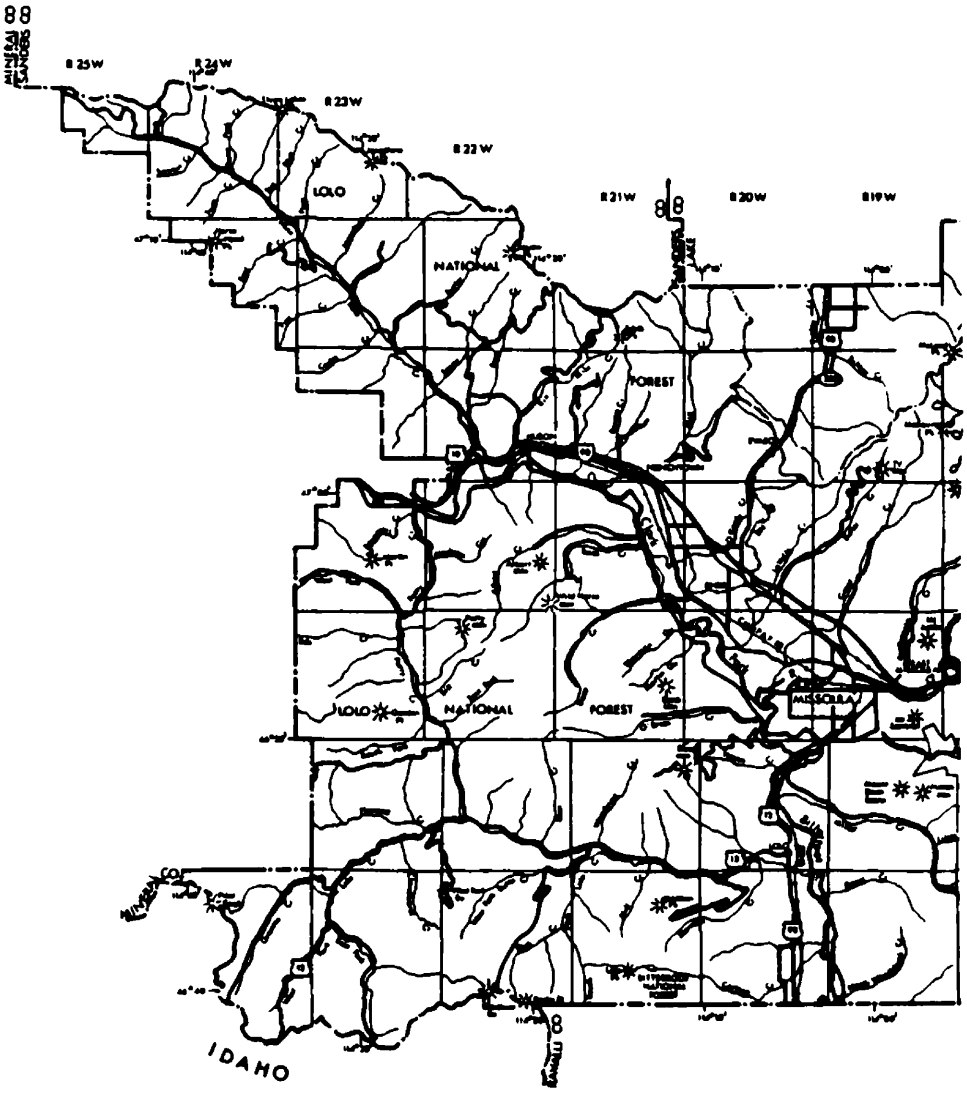

Figure 2: Vicinity map showing the Missoula Valley, Ninemile Valley, and the northern portion of the Bitterroot Valley, Montana

Valley, joining with the Clark Fork River approximately 6.5 km west of the City of Missoula.

The Missoula Valley floor is approximately 975 meters (3,200 feet) above mean sea level (msl) at its southeast end and approximately 900 meters (2,950 feet) above msl where Ninemile Creek joins the Clark Fork River. The valley flanks rise on average 900 meters (3,000 feet) above the valley floor, with some higher peaks. The flanks are dissected by numerous ephemeral and perennial tributaries of the Clark Fork River.

The southern half of the northeast flank of the Missoula Valley includes the field area for this study. The field area is bounded at its southeast end by Rattlesnake Creek and on the northwest by US93 which roughly parallels O'Keefe Creek. Its approximate boundary on the southwest is Interstate Route 90 (I90) and, on the northeast, the Lolo National Forest boundary (Plate 1).

Most of the field area is between 975 meters (3,200 feet) and 1,190 meters (3,900 feet) above msl, although several hills attain elevations in excess of 1,215 meters (4,000 feet). The field area is dissected by three tributary drainages of the Clark Fork River: Grant Creek, Butler Creek, and La Valle Creek. The creeks flow from northeast to southwest, draining the Rattlesnake/Jocko Mountains, alternate local names for the mountains north of Missoula. The lower reach of each creek is ephemeral where it onlaps the unconsolidated Quaternary sediments of the valley floor.

2.0 GEOLOGIC SETTING

2.1 PRE-TERTIARY UNITS

2.1.1 Precambrian Belt Supergroup

Rocks of the Precambrian Belt Supergroup underlie most of the Missoula Valley and probably all of the field area (Hall, 1968). Belt strata crop out north and northeast of the field area and near Waterworks Hill in the southern portion of the field area (Plate 1). In the Missoula Valley three formal stratigraphic groups comprise the Belt Supergroup: the Ravalli Group, the Wallace/Helena Formation, and the Missoula Group (Hall, 1968; Ort, 1992). Belt units are not differentiated on the geologic map presented in this study (Plate 1), but they comprise red, purple and green argillaceous siltite, argillite, and local units of quartzite and carbonate-bearing beds. For further description of the groups and formations that comprise the Belt strata in the Missoula area, the reader is referred to Hall (1968), Watson (1984), and Ort (1992).

2.1.2 Cambrian Rocks

Cambrian rocks are not found in the field area but do crop out on the opposite, southwest valley flank in the northern half of the Missoula Valley. The Albert Creek thrust fault, a Laramide feature (Hall, 1968), traces along the southwest valley flank here, and the Cambrian rocks are exposed northeast of the fault trace, in the footwall block. Smaller outcrops of both Cambrian and Precambrian rocks are exposed in the middle of the valley (Hall, 1968), midway between Missoula and Frenchtown, as a consequence of further faulting and fluvial downcutting. The Cambrian rocks consist of at least three formations and are predominantly carbonates (Hall, 1968). For more precise outcrop location and stratigraphic description the reader is referred to Hall (1968).

2.2 REGIONAL TERTIARY STRATIGRAPHY

2.2.1 Eocene Volcaniclastics and Basal Conglomerate

Significant Eocene volcanic fields in the Northern Rockies include the Absaroka-Gallatin field in northwest Wyoming and southwest Montana, the Challis field in east-central Idaho, and the Lowland Creek field at the northern extent of southwest Montana.

South of Missoula, middle Eocene rhyolite flows, tuffs, and mudflow deposits found in the Bitterroot Valley are considered Challis equivalents (Fritz and Harrison, 1985). In the Deer Lodge Valley, approximately 100 km southeast of Missoula, the flows and volcaniclastic deposits of the middle Eocene Lowland Creek Volcanics crop out and are found in the subsurface (McLeod, 1987).

McMurtrey, et al. (1965) documented volcanic rocks at the northwest end of the Missoula Valley which cap Belt strata. However, McMurtrey, et al. (1965) provided no description of the rocks and simply classified them as Tertiary in age. Hall (1968) mapped rhyolitic welded tuff at the northwest end of the Missoula Valley, near the confluence of Ninemile Creek and the Clark Fork River, but gave an uncertain Tertiary age for the deposit. However, he implied that the deposit was Oligocene or older when he cited McMurtrey et al. (1965) as observing detritus of the tuff in "Oligocene (?)" deposits in the Missoula Valley. Sears (1985) confirmed this stratigraphic position with a K/Ar date of 50 ma (middle Eocene), obtained from sanadine crystals in the tuff.

Basal conglomerates locally separate the Tertiary from pre-basin bedrock (Fields et al., 1985). According to Fields et al. (1985), the conglomerates represent early Tertiary basin formation; they were derived from previous extensional fault-bounded uplands.

In the Missoula Valley, conglomerate was observed intertonguing basal Tertiary deposits in several uranium test wells drilled as part of a United States Department of Energy study (Fields et al., 1985). However, it is uncertain whether these rocks are basal conglomerate or a coarse-grained facies within the lower Tertiary unit.

2.2.2 Renova Formation

Robinson (1963) applied the name Bozeman Group to the Tertiary strata seen in the basins of western Montana. Through observation and research of various basins in southwest Montana, Kuenzi and Fields (1971) recognized two distinct sedimentary units within the Bozeman Group which were separated by a regional unconformity. They subdivided the Bozeman Group into two formations and named the lower fine-grained unit the Renova Formation, after the town of Renova located in the Jefferson River basin of southwest Montana (Kuenzi and Fields, 1971).

At its type section in the Jefferson basin, the Renova Formation consists of alternating beds of micrite, montmorillonitic mudstone, vitric siltstone, vitric arenite, arkose, and minor conglomerate. The predominant colors of the fine-grained rocks are yellowish-grey and grayish-orange (Kuenzi and Fields, 1971). Fields et al. (1985) broadened the lithology somewhat, informally dividing the formation into upper and lower parts. The lower part contains siltstone, minor amounts of locally-derived conglomerate, air-fall and

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reworked deposits of ash, local volcanic flows, and coal. The upper part contains large amounts of volcaniclastics (mostly ash), montmorillonitic mudstone, and scattered lenses of coarse deposits (Fields et al., 1985).

Before and since Kuenzi and Fields (1971) named the Renova, considerable debate has arisen as to whether the formation was deposited in one large regional depression or in a series of broad, subparallel, occasionally interconnected basins. Kuenzi and Fields (1968) recognized the correlative similarity of the lower Bozeman Group in different basins of southwest Montana, claiming the basins were "evidently geographically continuous at the time of deposition." However, Kuenzi and Fields (1971) then stated the pre-Renova erosion surface was dissected and irregular in the ancestral Jefferson River basin and that by late Eocene (earliest Renova deposits) the Jefferson and adjacent basins had developed and were locally receiving sediments. Thus Kuenzi and Fields (1971), though not stating it outright, interpreted the Renova as a multi-basinal deposit.

Fields et al. (1985) further emphasized this, stating that delineation of basins began in the early to middle Eocene when extensional forces replaced Laramide compression. Erosion that preceded deposition of the Renova Formation was extensive; however, basins were not well developed, occasionally interconnected (depending on the influx of ash which blocked through-going drainages), and were only beginning to inherit their subparallel alignment (north-south) from Laramide folding and faulting (Fields et al., 1985). They also cited the fossil record as further evidence of a multi-basinal setting: "...when compared on the species level, [the mammalian fossils] show considerable endemism during the Arikareean, even among individual basins within western Montana and eastern Idaho, thus indicating local barriers to migration" (Fields et al., 1985).

However, McDowell and Fritz (1993) postulated a single basin as the depositional environment of the Renova Formation. In southwest Montana, in what is termed the Dillon/Renova basin, they cite a 200 kilometer-long, west-to-east thinning of Renova stratigraphy as evidence of blanket deposition (McDowell and Fritz, 1993). And Fritz and Sears (1993) claim the Renova Formation blanketed much of southwest Montana, referring also to the Dillon/Renova basin. Janecke (1994) cites Fritz and Sears (1993) to bolster her argument for a proposed Eocene to Oligocene rift zone running through eastern Idaho and western Montana; she speculates that a river transported volcaniclastics from the rift zone to a broad lowland east of the rift shoulder, a lowland she calls the Renova Basin. The rift may pan northward into the Bitterroot and Missoula Valleys which would define two separate depositional systems: a rift valley and a rift shoulder (Renova Basin).

North and west of Janecke's (1994) Renova Basin is the Arikareean (late Oligocene to early Miocene) Clark Fork basin as defined by Rasmussen (1989). Here, upper Renova was deposited over a large depositional area with through-going drainage; today, the tilted and eroded remnants of the basin are found in the Blackfoot, Flint Creek, Deer Lodge and Divide intermontane basins of western Montana (Rasmussen, 1989). Though the outlet of the Clark Fork basin is unknown, Rasmussen (1989) surmised that it led to the northwest, eventually joining with the ancestral Columbia River.

Because of these varied interpretations and because the formation name Renova is based on deposits found in southwest Montana, there is confusion as to what to call the lower Tertiary deposits seen in basins to the north. Within the Missoula Valley, the terms "Renova Formation equivalent," "Oligocene-Miocene," and "Tertiary deposits, undifferentiated" have been applied to the Tertiary strata (Woessner, 1988; Geldon, 1979; Van der Poel, 1979, among others).

In the Missoula Valley, where the light-colored, ash-rich beds of the lower Tertiary unit resemble the Renova Formation of southwest Montana, much of the confusion stems from age uncertainty. But Fields et al. (1985), in their discussion "Renova Formation and equivalents," claim plant fossils found in the Missoula and other basins provide ages ranging from Eocene to Miocene. More recently, Shane (1995) has radiometrically dated an ash bed within the field area of this study at 39 ma, late Eocene.

The lower Tertiary unit is found along the northeast, faulted margin of the Missoula Valley. In addition to grey, light grey and orange-brown siltstone, sandstone, and montmorrilonitic mudstone, the unit contains significant amounts of conglomerate, coal (once mined for railroad and domestic use [Fields et al., 1985]), and air-fall ash. More discussion on the lithology of this unit is presented in the Field Investigation section of this report.

2.2.3 Sixmile Creek Formation

Robinson (1963) assigned the very coarse-grained, later-Tertiary deposits seen in the Three Forks region of southwest Montana to the upper portion of the Bozeman Group.

However, he provided a relatively sparse description of the upper Bozeman Group when compared to that of the lower portion--what was to be named the Renova Formation by Kuenzi and Fields (1971). Separately, the younger deposits were considered incoherent, and therefore upmappable, and fossil evidence provided an uncertain age range of late Oligocene to early Pliocene (Robinson, 1963).

Working a few miles to the north, Robinson (1967) found much better exposure of the rocks in the Toston quadrangle. Their age was confined to Miocene and Pliocene, and the rocks were dubbed the Sixmile Creek Formation for the Sixmile Creek, a Missouri River tributary that flows within the quadrangle and exposes the rocks well (Robinson, 1967).

At its type section the formation consists of over 1,200 meters (4,000 feet) of basin deposits (coarse and tuffaceous conglomerate, sandstone, air-fall ash, minor paludal strata); 300 meters (1,000 feet) of sand and gravel deposited by a perennial, through-flowing stream; and 240 meters (800 feet) of fanglomerate and sandstone with an orange-red clay matrix (Robinson, 1967). Robinson (1967) suspected an angular unconformity between the Sixmile Creek Formation and the lower Bozeman Group though he could not clearly decipher the contact. A marked angular unconformity was observed where the Sixmile Creek Formation onlapped pre-Tertiary rocks, and thin Quaternary sediments were seen unconformably overlying the Sixmile Creek Formation (Robinson, 1967).

Kuenzi and Fields (1971) extended the formational name to the later Tertiary coarse-grained rocks they saw in the Jefferson basin and confirmed the angular unconformity between the Sixmile Creek Formation and the Renova Formation (formerly the lower Bozeman Group) suspected by Robinson (1967). Additionally, they correlated the Sixmile

Creek Formation with deposits in other Montana basins including Flint Creek, Deer Lodge, and the Bitterroot (Kuenzi and Fields, 1971). The formation's time of deposition was refined to between late Miocene and late middle Pliocene. Kuenzi and Fields (1971) suggested deposition may have continued through the Pliocene and possibly into the Pleistocene, but the unconformable relationship between the Tertiary formation and Quaternary sediments made this uncertain and probably unlikely.

Kuenzi and Fields (1971) noted that the Sixmile Creek Formation is easily distinguished from the Renova Formation either by grain size or by a color change from the lighter shades of the Renova Formation to darker orange and browns. However, the unconformable contact between the Sixmile Creek Formation and Quaternary deposits in many instances is impossible to decipher because much of the Quaternary may represent reworked Sixmile Creek Formation (Kuenzi and Fields, 1971). Locally, the Sixmile Creek Formation may be thinned to a veneer as a consequence of Pliocene pediment formation (Fields et al., 1985), obfuscating the significance of the deposit; the Pliocene erosion removed much of the Sixmile Creek Formation from valley flanks.

Kuenzi and Fields (1971) interpreted the Sixmile Creek Formation as a complex system of strong ephemeral and perennial streams; overbank deposition was common, and coarse detritus and mud flowed from adjacent, developing fault-block mountains, creating alluvial fans that intertongued with the fluvial deposits. Deposits were mostly locally-derived. This interpretation fits well into the regional tectonic history, beginning with the Renova/Sixmile Creek unconformity.

The Renova/Sixmile Creek unconformity is observable in most of the basins of western Montana (Rasmussen, 1973). It commonly represents a hiatus of nearly 3 million years, from approximately 17 ma to 20 ma (late early Miocene) (Fields et al., 1985). The unconformity has been correlated to other areas of the western United States, and its timing coincides with (and is probably related to) the onset of the Basin and Range extensional regime (Fields et al., 1985).

Basin and Range extension occurred within a compressional-arc setting. The compressional arc had initiated back-arc extension in the early Eocene (Chadwick, 1985). Back-arc extension increased in the late early Miocene, marking the onset of Basin and Range extension (Fields et al., 1985). A widely-held theory for the increased extension is that the spreading ridge which generated the slab to be subducted beneath the North American plate was itself subducted in the late Oligocene (Atwater, 1970). Thus, the subducted ridge, the East Pacific Rise, began to interplay with the existing back-arc extension during the Miocene, and regional extension increased, imprinting the Basin and Range regime onto the western United States landscape (Rasmussen, 1973; Chadwick 1985; Miall, 1990).

Early Basin and Range extension peaked during the Miocene and regional sedimentation of locally-derived coarse clastic deposits such as the Sixmile Creek Formation began (Fields et al., 1985). Deposition of the Sixmile Creek Formation continued into and possibly through the Pliocene (Kuenzi and Fields, 1971), but then extension again intensified in the region of western Montana and eastern Idaho.

This second episode of renewed extension is due to the complete cessation of compressional influence on the northern Rocky Mountain area (Fields et al., 1985). Subduction continued off the coast of northwest United States, as it does today, but its tectonic influence did not extend much farther east than the Cascade Ranges of Northern California, Oregon and Washington (Chadwick, 1985). Consequently, in the northern Rockies, the Basin and Range regime became purely extensional during the Pliocene. This episode has been marked in western Montana by an erosional unconformity atop the Sixmile Creek Formation and the creation of extensive pediment surfaces (Fields et al., 1985).

On the northeast flank of the Missoula Valley, coarse conglomerate is observed in unconformable contact with the lower Tertiary unit. The conglomerate closely resembles the lithology of the Sixmile Creek Formation, but age evidence is lacking. However, in the Bitterroot Valley which drains into the Missoula Valley from the south, slope-draping Sixmile Creek Formation deposits yielded a horse tooth fossil of Pliocene age (Konizeski, 1958). Based on its lithology, the observed unconformable contact with the lower Tertiary unit, and its regional proximity to Sixmile Creek Formation in the Bitterroot Valley, the coarse conglomerate is considered upper Tertiary.

Deciphering the upper Tertiary unit from Quaternary deposits in the Missoula Valley is formidable; lithologies are very similar. On some slopes the unit has been reduced by pedimentation, and commonly the thin remnants of the unit are obscured by younger alluvium or colluvium. Also, boulders and cobbles of Belt rocks are distributed over several areas of Missoula Valley's northeast flank. These rocks have been interpreted as erratics, rafted in on icebergs which may have plowed the waters of Glacial Lake Missoula during the Quaternary (Alden, 1953; McMurtrey et al., 1965; Van der Poel, 1979). But previously the distribution of these large rocks was only cursorily examined; based on this study it seems some of these rocks are part of the upper Tertiary unit. The distribution of these rocks is discussed in the Field Investigation section of this report.

Delineating the upper Tertiary unit from the lower Tertiary unit in the Missoula Valley is straightforward, but exposures are limited. Nonetheless, some excavations in the field area provide clear view of upper Tertiary red-brown coarse conglomerate resting unconconformably on the light-colored, finer-grained lower Tertiary unit (Figure 3). Additional facies descriptions of the upper Tertiary unit in the Missoula Valley are included in the Field Investigation section of this study.

2.3 QUATERNARY SEDIMENTS

2.3.1 Glacial Lake Missoula Deposits

During the Pleistocene, continental glaciers encroached from the north. On the Clark Fork River, near the Montana-Idaho state line, an ice lobe crossed the main path of glacial melt water draining from regions west of the continental divide (Alden, 1953). The ice dam created Glacial Lake Missoula, a body of water covering an area of about 5,400 square km which inundated many of the basins of west-central Montana, including the Missoula Valley (Hall, 1968). The glacial lake drained when the ice dam floated and ruptured; it reformed, at least 36 times, when subsequent ice lobes repeatedly blocked the Clark Fork River at the same location (Pardee, 1910; Alt and Hyndman, 1990). In

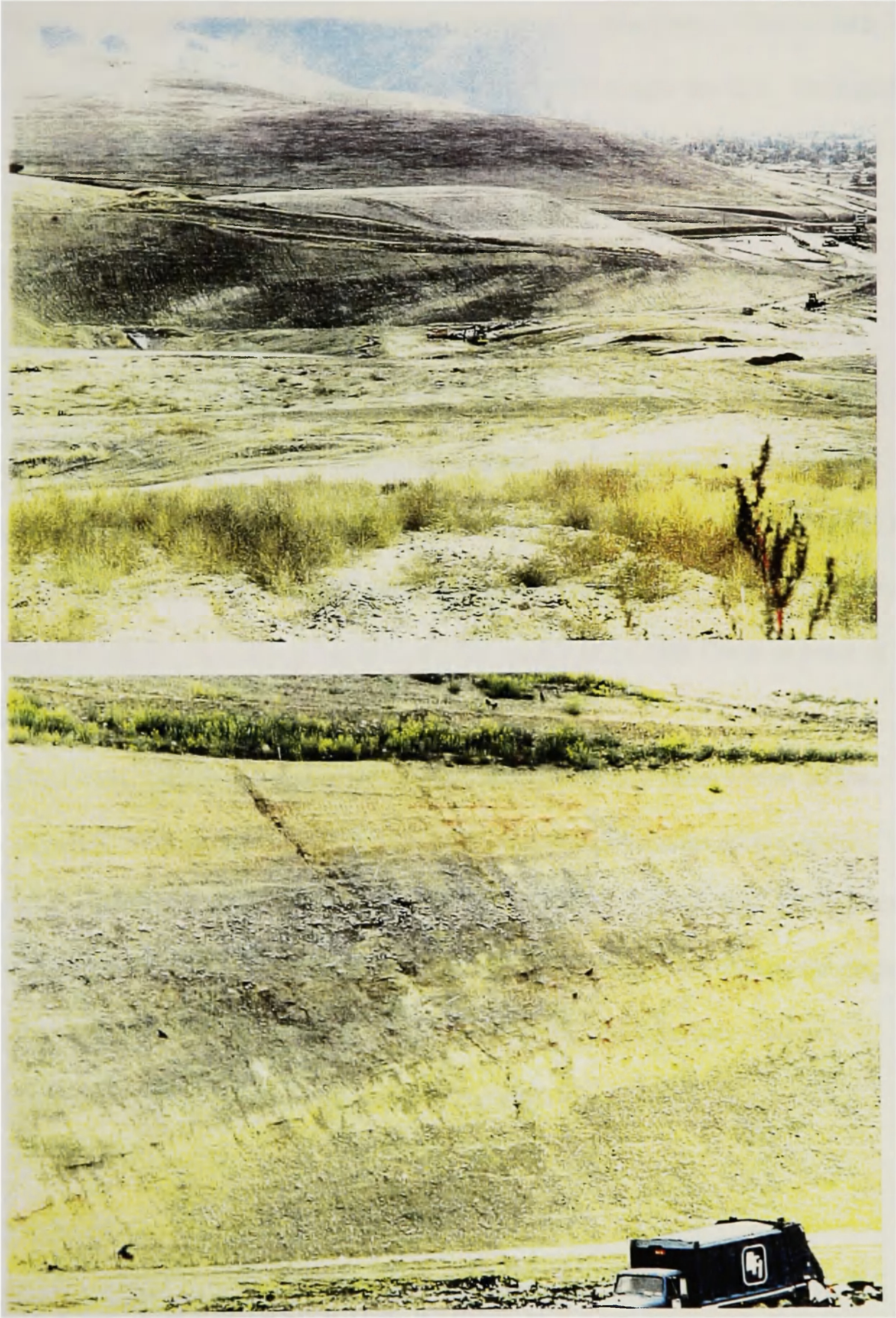

Figure 3: Angular unconformity between upper and lower Tertiary units exposed on the southeast sidewall excavation of the BFI landfill cell

Missoula, faint shorelines representing different levels and incarnations of Glacial Lake Missoula can be seen on the west faces of Mount Jumbo and Mount Sentinel. The highest shorelines are at 1,265 meters (4,150 feet) above msl, slightly less than 305 meters (1,000 feet) above the City of Missoula.

Glaciolacustrine silt and clay were deposited throughout the area covered by Glacial Lake Missoula. In the Missoula Valley the fine-grained deposits are found in the river terraces that are generally between 15 and 30 meters above the present bed of the Clark Fork River (McMurtrey et al., 1965). McMurtrey et al. (1965) reported an average thickness of the glaciolacustrine deposits of 27 meters (90 feet). For this project the Lake Missoula silts and clays were not differentiated from other Quaternary deposits, but they were encountered in the lower terraces west of the mouth of LaValle Creek and east of US93.

Various authors have interpreted cobbles and boulders of Belt strata strewn on the northeast flank of the Missoula Valley as erratics, dropped by icebergs drifting about Glacial Lake Missoula (Alden, 1953; McMurtrey et al., 1965; Van der Poel, 1979). But in the vicinity of Grant Creek, I interpreted the distribution of Belt rocks seen on the slopes as part of a boulder-dominated conglomerate facies of the upper Tertiary unit, as discussed in the Field Investigation section of this report.

2.3.2 Alluvium

Alluvium within the Missoula Valley and from the tributary Clark Fork drainages consists of sands and gravels eroded from Tertiary and pre-Tertiary rocks and includes silt and clay from reworked Glacial Lake Missoula deposits. These river terrace and drainage deposits have been mapped together as Quaternary alluvium.

Within the drainages of the field area, Smith (1992) reported alluvium to 75 meters (246 feet) below ground surface (bgs) near the mouth of Grant Creek and in the common broad valley drainage for Butler and LaValle Creeks sand and gravel alluvium was reported to 65 meters (213 feet) bgs.

Thin Quaternary sand, gravel and cobble deposits mantle some areas of the northeast flank of the Missoula Valley. These deposits often thinly cover the lower Tertiary unit or represent reworked deposition of the upper Tertiary unit. Deposits of this type were ignored in favor of the Tertiary units underlying the cover.

2.3.3 Landslide Deposits

Several landslides were mapped within the field area. Most involved the slippage of the lower Tertiary unit, and commonly, significantly thick deposits of the coarse-grained upper Tertiary unit were observed in the vicinity of the landslide. Most of the slides are inactive, and the age of last movement is uncertain. Hall (1968) speculated that landsliding occurred shortly after the draining of Lake Missoula when water saturation was high. Discussion of Quaternary landslides is included in the Field Investigation section of this report.

2.4 MISSOULA VALLEY STRUCTURE

Trending northwest across the subparallel, north-south alignment of western Montana's basins is the Lewis and Clark Line, a shear zone that stretches from east of the continental divide near Helena, through the Idaho panhandle into eastern Washington (Sears, 1995; Alt and Hyndman, 1990; Harrison et al., 1986). Within this zone is the Ninemile Fault which delineates the northeast flank of the Missoula and Ninemile Valleys. The fault trace indicates that the fault dips steeply to the southwest (Hall, 1968). The complexity of the shear zone and the Ninemile fault is significant; movement on the shear zone has been interpreted both as dextral and sinistral, and the Ninemile fault has been interpreted variously as thrust, dextral, sinistral, and normal (Yin and Oertel, 1995). This confusion stems from the long history of the shear zone through changing tectonic regimes.

The northeast dip of the lower Tertiary unit exhibits the most recent movement on the Ninemile fault (Hall, 1968; this study). The fault was active during and subsequent to the deposition of the unit. The fault has not moved since the Miocene; the upper Tertiary unit offlaps pre-Tertiary rocks northeast of the fault trace and extends south, across the fault (Plate 1). Additionally, one observed facies of the unit is horizontal and in angular-unconformable contact with the lower Tertiary unit (Plate 1).

Local indications of the dextral component of movement along the Ninemile fault are difficult to document. Hall (1968) circumspectfully presents a syncline within the lower Tertiary unit in the vicinity of O'Keefe Creek (US93) as evidence of right-lateral motion. The shallow-plunging syncline was observed in this study, and its formation can be envisioned by oblique downthrowing of the southern block. However, at best the syncline is only circumstantial evidence of dextral-oblique slip.

3.0 FIELD INVESTIGATION

3.1 TERTIARY STRATA AT BFI LANDFILL

3.1.1 Description of Landfill Refuse Cell and Tertiary Strata Exposure

The BFI landfill lies within the lower northeast flank of the Missoula Valley, due north of Missoula (Plate 1). The landfill opened in December 1968 and was originally managed by City Disposal Company. BFI purchased the facility from City Disposal Company in 1979. In 1995 BFI began excavating a new refuse cell within the landfill property. The cell is a rectangular-shaped basin with its long axis is oriented on a northeast-southwest line (Figure 4). Its base is approximately 90 meters by 200 meters. After the installation of a multi-layered protective lining, the cell began receiving refuse in December 1995. It is currently the main receiving cell at the landfill (Leiter, 1997).

The excavation of the cell removed approximately 45 vertical meters of the original topography. The base of the cell is founded into lower Tertiary strata, though the geology was concealed by the cell lining and refuse at the time of my field investigation. The northwest and southwest sidewalls of the excavation are cut into fill. The northeast and southeast excavation sidewalls expose approximately 100 meters of northeast-dipping lower Tertiary strata and about 12 meters of flat-lying upper Tertiary strata. The angular unconformity between the lower and upper Tertiary strata is exposed on the southeast excavation sidewall (Figure 3).

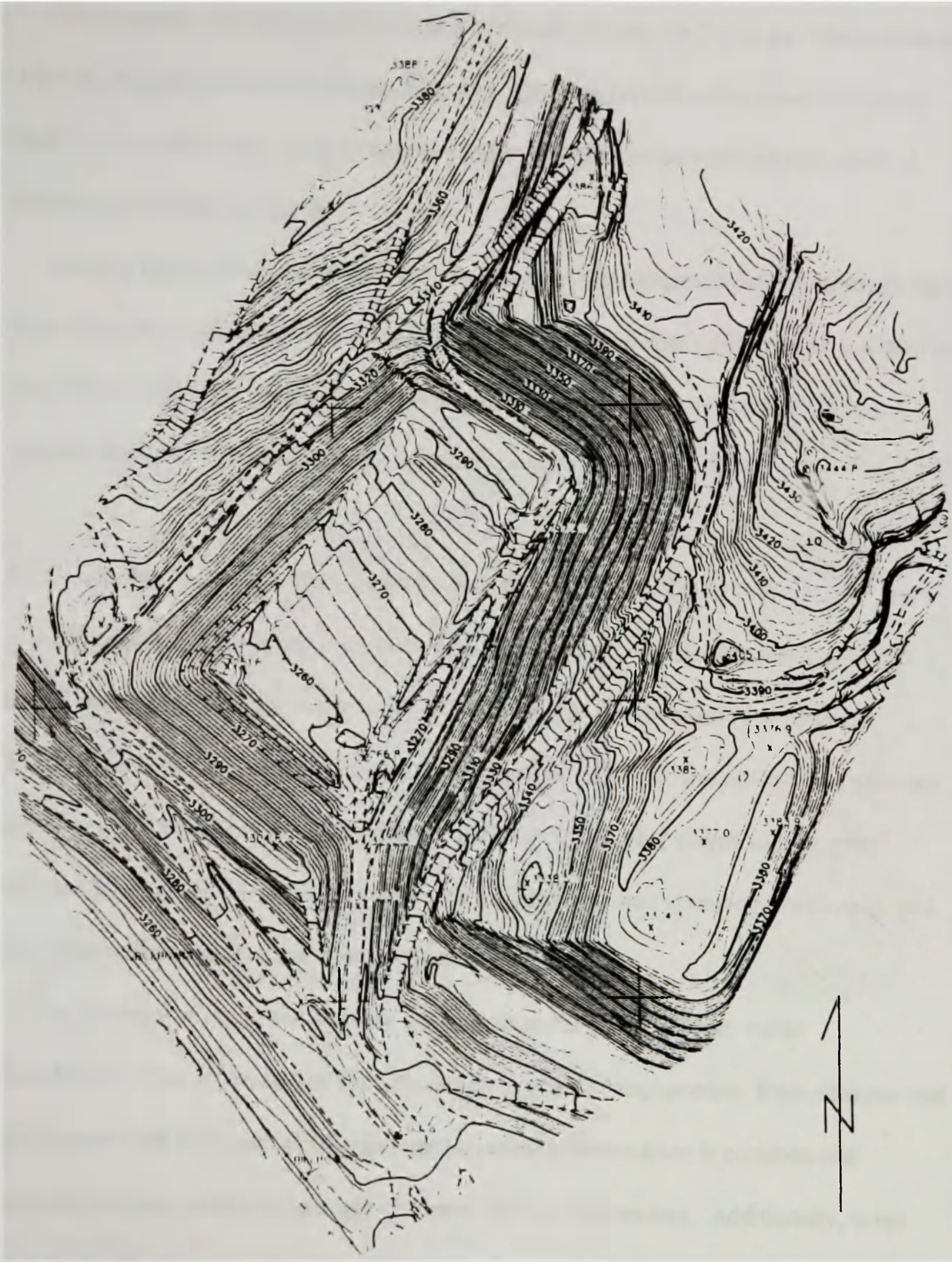

Figure 4: Grading plan of BFI Landfill cell (not to scale; elevations given in feet above mean sea level)

The northeast and southeast excavation sidewalls are cut at a 2:1 slope. The northeast sidewall is approximately 30 meters high, and the southeast sidewall is about 14 meters high at its southern end, rising to approximately 30 meters at its northern end where it adjoins the northeast sidewall.

Grading operations at the landfill are ongoing, and dimensions of the cell sidewalls have been altered as earth materials north of the landfill cell have been removed and are used to layer refuse in the cell. North of the northeast sidewall the earth-removal work has exposed about 85 additional meters of lower Tertiary strata (Figure 5).

3.1.2 Lithology of Lower Tertiary Strata Exposed at the BFI Site

I distinguished 17 lithologic subunits in the lower Tertiary strata exposed at the BFI site. On average, the units strike northwest, dipping to the northeast at 20 degrees. Thicknesses of the subunits vary along the excavation sidewalls, and at least two subunits are discontinuous within the span of their exposure. I compiled eleven stratigraphic columns to illustrate the relative positions of the subunits, their changing thicknesses, and the differing lithologies (Plate 2 and Appendix 1).

The lithology of the lower Tertiary deposits exposed at the BFI site varies considerably. The strata ranges from claystone to coarse conglomerate, from siltstone and sandstone to ash and coal. Brick-red lateritic staining/cementation is common and localized calcium carbonate strongly cements some conglomerates. Additionally, some finer-grained beds contain lenses of coarser deposits, and channel scour of fine-grained

Figure 5: Additional lower Tertiary strata exposed north of BFI Landfill cell

beds is not uncommon. The total section measured is 184 meters (Plate 2). All subunits are described in Appendix 1.

Several of the subunits are worth noting. Subunit 6 consists of 11.5 meters of conglomerate which fines into 3.5 meters of sandstone. The conglomerate is grey-brown to reddish grey-brown, clast-supported, and contains clasts to 20 centimeters (cm) in diameter though most are about 5 cm. The clasts are mostly subrounded and include argillites (green, red-purple, grey, and light brown), quartzites (red-purple, pink, grey, and green), and shale (light brown and grey). It is locally cemented with calcium carbonate and its matrix is fine to coarse sand. The conglomerate fines to a fine-grained sandstone which in turn is capped by two meters of light grey to white ash tephra (Subunit 7). A 2 cm thick coal seam is within the tephra. Subunit 7 is scoured deeply by Subunit 8, a well-cemented conglomerate which displays a thickness variation of 18(?) to 33.5 meters (Figure 6; Plate 2; Appendix 1). Subunit 8 contains weak, northwest-directed imbrication. Argillites and quartzite clasts are most common, but rare, very weathered and well-rounded granitic clasts are also present. Local calcium carbonate cementation is present in this subunit.

Subunit 17 is at the top of the section and is distinctive for its color; I informally dubbed this subunit "the White Beds." The subunit is 10 meters thick and consists of tuffaceous silty sandstone; the lower half of the unit includes tuffaceous, conglomeratic interbeds less than 1 meter thick (Plate 2 and Appendix 1).

Figure 6: Lower Tertiary strata exposed at the BFI Landfill cell:
scour of subunit 7 by subunit 8

3.1.3 Lithology of the Upper Tertiary Strata Exposed at the BFI Site

The upper Tertiary unit is observable on the southeast sidewall where it unconformably overlies the lower Tertiary unit (Figure 3). Its lithology is displayed graphically on Plate 2 and described in Appendix 1. The unit was measured to 12 meters. It is certainly thicker than 12 meters, but grading operations have removed much of the unit.

The unit consists of a basal cobble conglomerate up to 2 meters thick. The unit fines upward to a sandstone and then is followed by a series of pebble conglomerates, sandstones and siltstones. Each bed within the unit is conformable with overlying and underlying beds, and the unit is horizontal.

The cobble conglomerate at the base of the unit lies in an approximate 20-degree angular unconformity with the lower Tertiary unit. The cobble conglomerate is poorly cemented, clast-supported, and has clasts to 60 cm in diameter. Clasts are subrounded and include quartzite (red, white, grey, and grey with pit marks) and some mafic igneous rocks. Weak imbrication is observed when the conglomerate is viewed from a distance, though measurement is difficult; I visually estimate the flow direction indicated by the imbrication to be directed to the northwest.

3.1.4 Continued Evolution of Tertiary Strata exposures at the BFI Site

Earth materials are continually being removed as part of the daily operations at the BFI landfill. Additionally, another landfill cell is planned to the north of the currently active cell. Final excavation and lining of this cell is scheduled for 1998 (Leiter, 1997). Further insight into the lithology and evolution of the Tertiary strata in the Missoula Valley can be garnered from new exposures made by grading operations at the BFI landfill.

3.2 FIELD GEOLOGIC MAPPING

3.2.1 The Search for Exposures of the Lower Tertiary Unit

Outcrops of Tertiary strata in the field area are rare. Brush, thin alluvial soil and colluvium cover most of the slopes. But beneath the cover the average strike of the lower Tertiary unit is northwest, along the trend of the valley flank. The BFI site, at the southern end of the field area, provided a starting point, a place to compile nearly 200 meters of lower Tertiary stratigraphy. Working mostly northwest from the BFI site I followed the trend of the valley flank and the strike of the lower Tertiary strata, searching for outcrops I could place within the lower Tertiary stratigraphy compiled at the BFI site. I hoped to identify distinctive subunits, marker beds such as Subunits 7 and 17 (Plate 2 and Appendix 1), and thick, uniform deposits, such as the Subunit 8 conglomerate, elsewhere in the field area.

Numerous lower Tertiary exposures were found (Plate 1), but placing any of these outcrops within the stratigraphic framework revealed at the BFI site was problematic. Outcrops of the strata typically are not as cleanly exposed as in the sidewall cuts at the BFI site. Predominantly, the outcrops measure only a few meters across, and commonly less than a meter of stratigraphy is revealed. Additionally, though the trend of the lower Tertiary unit is northwest, bedding strike and dip direction vary considerably between some outcrops (see Grant Creek drainage on Plate 1). Distinctive markers such as subunits 7 and 17 (Plate 2 and Appendix 1) could not be found beyond the limits of their exposures at the BFI site. Finally, the thickness of the lower Tertiary strata in the Missoula Valley is much greater than the 184 meters exposed at the BFI site. McMurtrey, et al. (1965) provide a questionable Tertiary thickness estimate of about 4,000 meters, and clearly the distribution of lower Tertiary outcrops seen in this study, coupled with the general orientation of the strata, reveal a thickness far greater than 184 meters (Plate 1). Nonetheless, outcrop lithologies were noted and illustrated on the geologic map (Plate 1) according to the following criteria.

Within the lower Tertiary unit, four main distinctions were made between outcrops. Conglomerate commonly crops out and much of it is similar to Subunit 8 (Appendix 1), particularly east of Grant Creek. Subrounded clasts typically within the conglomerate are green, red and grey argillites and quartzites derived from the Belt Supergroup. The overall color of the rock is red-brown, though this may vary to light brown. Localized calcium carbonate cementation is common. Outcrops of this conglomerate, with associated beds of sandstone, are mapped in red-brown on the geologic map (Plate 1).

A second lower Tertiary conglomerate type is distinct from the red-brown conglomerate because it is poorly lithified, includes clasts of mylonite, and is associated with sandstone. This conglomerate is light grey-brown, clast-supported, and loosely consolidated. Clasts are mostly subrounded pebbles with some cobble-sized clasts and include white, milky, and grey quartzites, rhyolitic and granitic clasts, and mylonite. This outcrop type, colored blue on the geologic map, is seen between Grant Creek and Butler Creek and northwest of Butler Creek, particularly along LaValle Creek (Plate 1).

Coarse to fine-grained sandstone and lesser amounts of siltstone and mudstone were encountered in various outcrops throughout the field area and are marked orange on the geologic map (Plate 1). These outcrops commonly exhibit bedding well, are light brown, light grey-brown or orange-brown, and range from well to poorly lithified. Coal seams are within some of the finer beds, though not commonly.

Tuffaceous deposits are very common in the lower Tertiary unit. Ash-rich beds ranging from claystone and mudstone to pebble conglomerate are typically exposed in road cuts, such as along I90. The beds are white, light grey, grey, and grey-brown. Coal seams and minor coal beds (less than 5cm thick) are observed in some outcrops. Exposed surfaces commonly exhibit a "popcorn" texture related to the hydration and desiccation within clay-rich (smectitic) beds. Conglomerates within the tuffaceous deposits are matrix-supported and occur as minor lenses or interbeds between more common siltstones and mudstones. Outcrops of the tuffaceous deposits are colored dark grey on the geologic map (Plate 1).

A grey-white ash bed, approximately 10 meters thick, crops out north of the BFI landfill. The bed is easily visible from a distance and was traced along a ridge flank for several hundred meters. The ash was radiometrically dated at 39ma (Shane, 1995). Because of its distinct exposure and age information, this deposit is accorded its own color, grey-white, on the geologic map (Plate 1).

3.2.2 Stratigraphy of the Lower Tertiary Unit

Beyond the limits of the BFI landfill, rare exposures of the lower Tertiary unit reveal more than several meters of stratigraphy. Three such outcrops, showing lower Tertiary thicknesses in excess of 10 meters each, were found in the field area. The first two can be placed in relative stratigraphic order. The third exposure, due to its proximity to the Ninemile Fault, is probably stratigraphically above the other two exposures, although its bedding strikes northeast and dips moderately southeast. This variation from the regional trend is probably due to local deformation caused by the Ninemile Fault.

The lowermost exposure is from a gravel pit excavation west of La Valle Creek (B 14-20-27a). Just over 16 meters of bedding have been exposed. Beds dip nearly due north at 15 degrees. At the base of the exposure is a pebble and cobble conglomerate in excess of 12 meters thick. It is light, rusty orange-brown to light grey-brown, mostly clast-supported, poorly cemented, and has a coarse sand matrix. The conglomerate contains clasts up to 15 cm in diameter though most are 5 cm or less. Clasts are subrounded to well-rounded and include quartzites (light grey, brown, pink), volcaniclastics (rhyolite), milky quartz, and mylonite. The conglomerate is imbricated, indicating a flow to the north. A three-dimensional exposure of a small channel scour (less than one meter wide) within the conglomerate also indicates a northerly trend. Four meters of fine to medium-grained sandstone overlie the conglomerate. The sandstone is light grey, weakly cross-stratified, poorly cemented, micaceous (muscovite), tuffaceous, well-sorted and contains quartz and plagioclase grains. The upper two meters of the sandstone contains two interbeds of light grey and light grey-green, tuffaceous siltstone and claystone. The exposure is capped by less than one-quarter meter of Quaternary alluvial cover.

The second exposure is on the east side of La Valle Creek, near the tip of the ridge that separates the upper stretches of La Valle and Butler Creeks (B 14-20-24b). Strata strike northwest and dip 37 degrees northeast. Assuming no faulting between exposures and an averaged planar relationship, the second exposure is approximately 1,200 meters up-section from the exposure at the gravel pit (B 14-20-27a).

The La Valle Creek exposure is actually due to an alignment of three, adjacent road cuts on La Valle Creek Road which reveal about 150 meters of the lower Tertiary unit. However, only the southernmost roadcut allows observation of deposits in-situ; deposits in the northern road cuts are so poorly consolidated that sloughing conceals bedding. Nonetheless, evaluation of the sloughed material indicates it was derived from a lithology similar to that exposed in the southernmost road cut.

The La Valle Creek exposure is predominantly conglomerate. It is grey-brown to light grey-brown, clast-supported, and contains mostly pebbles to 4 cm in diameter though some clasts are as large as 10 cm in diameter. Clasts are subrounded and include quartzites (pink, light grey, brown, white), slightly weathered porphyritic granite, and mylonite. Some clasts, in contact with other clasts, are fractured. Clast fractures radiate from contact points with other clasts. Thin (less than 3 cm), medium to fine-grained interbeds of light grey sandstone occur rarely. These beds are well cemented, exhibiting smooth bedding surfaces.

The third exposure is in the northwest corner of the field area where lower Tertiary strata have been exposed by a railroad cut (B 14-20-10da). Approximately 60 meters of strata are exposed. Bedding strikes northeast and dips 65 degrees southwest. The incongruity of bedding at this exposure with the regional trend of the lower Tertiary unit is probably due to faulting along the Ninemile Fault which is in close proximity to the exposure (Plate 1). This exposure is probably up-section from the second exposure (B 14-20-24b), though considering its incongruous orientation and the probability of multiple planes of movement defining the Ninemile Fault, it is uncertain how far up-section.

The lower 20 meters of bedding in the railroad cut consist of light brown to yellow-brown siltstone and mudstone. The strata are weathered and bedding surfaces are difficult to expose clearly. The overlying 20 meters consists of sandstone. The sandstone is light brown, fine to medium-grained, and very well cemented. The middle portion of the sandstone is tuffaceous. The sandstone fines into 20 additional meters of siltstone and mudstone similar to basal strata of the exposure. A thin coal seam (less than 3 cm thick) is exposed in this upper portion.

3.2.3 Stratigraphy of the Upper Tertiary Unit

As mentioned previously, deciphering the upper Tertiary unit from Quaternary sediments is difficult, and even ascribing certain deposits in the Missoula Valley to an upper Tertiary time frame is problematic because fossil evidence is lacking. At the BFI landfill stratigraphic position can be used to some extent: tilted lower Tertiary strata underlie more than 12 meters of flat-lying, coarse strata. The coarseness of the deposit, its angular unconformity with the underlying lower Tertiary deposits, its proximity to a faulted basin margin, and its incongruity with Quaternary drainages all allude to a kinship with the upper Tertiary Sixmile Creek Formation. But without datable evidence I can at best informally assign the deposit to the upper Tertiary.

Outside the BFI landfill, this unit is difficult to distinguish from Quaternary deposits of similar lithology. Differentiating between the two is difficult in the same way Kuenzi and Fields (1971) reported difficulty in distinguishing the Sixmile Creek Formation from Quaternary sediments: some Quaternary deposits were derived from reworking of the underlying coarse unit. Additionally, due to late Pliocene pediment formation that occurred throughout much of the western United States (Fields et al., 1985), commonly only a remnant veneer of coarse deposits mantles the lower Tertiary unit.

However, a gravel pit excavation on the east side of Grant Creek (B 13-19-5a) provides evidence of a significantly thick, coarse deposit overlying the lower Tertiary. Here over 35 vertical meters of nearly flat-lying pebble conglomerate are exposed. The conglomerate is brown to light brown, mostly clast-supported, and loosely consolidated. Clasts are subrounded though flat and tabular. Clasts are up to 20 cm in greatest dimension though most are 5 cm or less and include quartzites (banded pink, grey), argillites (red and green), and shale (light brown, white, light green). The conglomerate matrix ranges from silt to coarse, lithic-rich sand. The deposit appears massive when viewed from a distance, but closer inspection reveals small-scale channel fills and fining-upward sequences (generally less than 25 cm in either the horizontal or vertical dimension). Sloughing of this exposure is common due its poor consolidation.

Across a short Grant Creek tributary, boulders greater than one meter in diameter are strewn on the slope opposite the gravel pit excavation (B 13-19-5a and B 14-19-32d, Plate 1). Similarly, boulders are grouped in various locations within the field area but particularly on the slopes that flank either side of Grant Creek (Plate 1). Boulders are generally one to two meters in diameter, subangular to subrounded and are predominantly quartzite but also include siltite and argillite; they are derived from Precambrian lithologies as mapped by Ort (1992) in the headwaters of Grant Creek. The boulders are grouped so tightly in some locations that they are in near contact. In other locations the boulders are separated by several meters.

Coarse gravel, found as float, is typically associated with the grouped boulders. The gravel is well rounded, generally of the same lithology as the boulders, although clasts of sandstone and shale are not uncommon. In some locations the gravel is found on hill tops, up-slope from a grouping of boulders (B 14-19-28c and B 14-19-30). In other areas the gravel is found midslope between the boulders and outcrops of the lower Tertiary unit.

Certainly some of the gravel is associated with emplacement of the boulders and some of the gravel is associated with later processes. Differentiating between gravel types is difficult. However, in the field area Quaternary slopewash gravel and gravel distributed by late Pliocene pedimentation is thin, providing a mantle over older units that is commonly less than one meter thick. Road cuts near the top of the west flank of Grant Creek (B 14-19-30) show only gravel; more than 2 vertical meters are exposed, and no trace of underlying rock is revealed. The conglomerate/gravel exposed at the gravel pit excavation (B 13-19-5a) shows a thickness in excess of 35 meters.

The hill-top gravel, the conglomerate/gravel exposed in the gravel pit excavation and the distribution of the boulders on either side of Grant Creek indicate the existence of a significant facies deposited after the lower Tertiary unit, after faulting along the Ninemile Fault, and before late Pliocene pedimentation and Quaternary processes that developed the modern Grant Creek drainage. On the west side of Grant Creek, the basal contact of this facies of the upper Tertiary unit has a slight planar inclination toward the Missoula Valley (Plate 1). Assuming a nearly horizontal orientation, the facies measures approximately 150 meters thick, from its basal contact to the gravel-topped peak in the quarter section B 14-19-28c. Thus, the facies appears as a wedge of coarse clastic material, thick at its northern extent and thinning as it extends south toward the valley.

The boulder-dominated conglomerate facies also thins northwest and northeast of the flanks of Grant Creek; thinner, outlying exposures have been isolated by erosion. Northwest of Butler Creek only remnants of the upper Tertiary unit remain; fewer and smaller clusters of boulders lie over the lower Tertiary unit. Gravel associated with the emplacement of the boulders was not found. Gravel clasts in the float around the boulders included clasts of mylonite and thus were attributed to the lower Tertiary unit.

Some of these boulder clusters might be attributed to emplacement via ice-rafting during the Quaternary when Glacial Lake Missoula inundated the valley (Alden, 1953); all boulder clusters are found below the high shoreline mark of 1,265 meters (4,150 feet) above msl. But I mapped all the boulder groupings I encountered as upper Tertiary for the following reasons: 1) the boulders are derived from Precambrian lithologies found in the Grant Creek headwaters; 2) the boulders are found in clusters and the clusters are more numerous and cover a broader expanse along the flanks of Grant Creek and are smaller and fewer away from Grant Creek; and 3) associated gravel is found within, upslope and downslope from the boulder clusters.

3.3 GEOLOGIC STRUCTURE

3.3.1 Orientation of Tertiary Strata

Throughout the field area the lower Tertiary unit trends northwest and dips gently to moderately to the northeast. Variations from this trend are seen in the Grant Creek drainage (B 14-19-32) and in the road cuts of a development between the mouths of Butler and Grant Creeks (B 14-20-36) (Plate 1). In these locations I could not discern a structural grain to explain the assortment of bedding plane attitudes, primarily due to a lack of coherent exposure. But where bedding orientations vary from the regional trend the lithology is constant; all exposures consist of fine-grained and tuffaceous strata, primarily siltstones and claystones.

Because the regional orientation of the lower Tertiary unit remains constant elsewhere through the field area it does not seem likely that the variety of bedding attitudes at the cited locations represent deep-rooted deformation. Rather, it is probable that secondary, near surface deformation occurred subsequent to the northeast regional tilting. Finer-grained, tuffaceous, poorly indurated beds, retaining a greater amount of moisture than overlying and underlying coarse beds, likely slumped after tilting and exposure. Smectitic clay resulting from the diagenesis of the more ash-rich beds would add to the incompetency of these deposits, increasing the likelihood of slumping. It is also possible that movement occurred after one or more of the Quaternary draining episodes of Glacial Lake Missoula, as suggested by Hall (1968); the tilted beds would have been saturated but no longer buoyed by the lake. Finally, the contorted beds may be remnants of earlier landslides, landslides that occurred before and shortly after the time of Glacial Lake

Missoula. Such landslides may not be recognizable however because subsequent erosion has removed their geomorphic features.

The orientation of the upper Tertiary unit at the BFI landfill is horizontal. The upper Tertiary conglomerate/gravel exposed at the Grant Creek gravel pit excavation (B 13-19-5a) is near-horizontal. Also at Grant Creek, the basal contact of the upper Tertiary unit with the lower Tertiary unit is inclined slightly to the south-southwest (Plate 1).

3.3.2 Folds and Faults within the Lower Tertiary Unit

In the northwest portion of the field area, beds of the lower Tertiary unit show a strike to the east-northeast and dip moderately to the south-southeast (B 14-20-10) (Plate 1). The bedding orientation is certainly contrary to the regional trend, but the beds define the northern limb of a syncline whose axis more or less aligns with the regional, northwest-southeast strike of the lower Tertiary unit and with the strike of the Ninemile Fault. The syncline axis plunges shallowly to the east-southeast. The orientation of the axis can only be approximated using the regional strike and dip of the lower Tertiary unit; there are no proximal outcrops exposing the southern limb of the fold.

McMurtrey et al. (1965) noted the anomalous orientation of Tertiary bedding in this location, claiming it was related to right-lateral movement along the Ninemile Fault, but no direct evidence was cited. In trying to decipher the claim of McMurtrey et al. (1965), Hall (1968) identified the syncline and cautiously stated that the orientation of the strata and the shallow easterly plunge of the fold could have formed from oblique, right-lateral downthrowing of the hanging wall. However, the evidence for such movement along the fault is far from conclusive. Approximately two and one half kilometer to the southeast, along the trace of the Ninemile Fault, an outcrop of lower Tertiary conglomerate has a strike roughly parallel to the Ninemile Fault and a 25 degree dip to the southwest (B 14-20-13b). The strata orientation here could have resulted by drag-folding from purely normal movement along the Ninemile Fault, or it could be related to smaller-scale deformation within the Ninemile Fault zone. It might also be another outcrop of the northern limb of the easterly-plunging syncline, though, given its dip which is less steep than those beds closer to the axis of the syncline, this seems unlikely.

Due to the roughly parallel alignment of the syncline axis with the Ninemile Fault trace, I conclude the syncline is a drag fold caused by normal movement along the Ninemile Fault. But it is indeterminate whether fault movement contained a dextral-component of slip.

McMurtrey et al. (1965) implied the existence of multiple parallel faults striking along the northeast flank of the Missoula Valley, from the toe of the valley flank to the trace of the Ninemile Fault (Figure 5 in McMurtrey et al., 1965). The evidence McMurtrey et al. (1965) provide for such a system of parallel faulting is "the apparently great thickness of Oligocene (?) strata [lower Tertiary unit] and the orientation of Pliocene (?) strata [upper Tertiary unit] near the mouth of Butler Creek."

No indication of such a series of faults was seen in this investigation. Rare displacements of the lower Tertiary unit were seen at the BFI site, but these were single shear planes recording less than 1/4 meter of normal movement. Only one shear plane within Tertiary strata was found outside of the BFI site; north of the landfill (B 13-19-4c), a shear plane produced about 1/3 meter of normal displacement.

McMurtrey et al. (1965) estimated that nearly 4,000 meters (13,000 feet) of Tertiary strata occur in the area of Butler and La Valle Creeks. But it is unclear how such an estimate was obtained. I crudely estimated the thickness of the lower Tertiary unit to be 1,600 meters. This was done trigonometrically using an average northeasterly dip of 22 degrees and measuring, parallel to the dip direction, the horizontal distance between the toe of the Missoula Valley flank and the point where the trace of the Ninemile Fault crosses Butler Creek (the faulted contact between the lower Tertiary unit and the Belt Supergroup (Plate 1). I considered the change in elevation to be negligible.

The 1,600 meter thickness of the lower Tertiary unit is greater than thicknesses of time-equivalent (Renova Formation) strata measured in other basins. In the Toston Quadrangle in southwest Montana, Robinson (1967) measured 1,250 meters (4,100 feet) of Oligocene strata from the lower Bozeman Group (Renova Formation), and Kuenzi and Fields (1971) measured over 1,050 meters (3,500 feet) of the Renova Formation in the Jefferson basin of southwest Montana. Nonetheless, 1,600 meters is well within the magnitude of these thicknesses of early Tertiary basin deposits. Therefore, it is not warranted to propose a series of parallel normal faults in order to explain the amount of lower Tertiary strata that occur on the Missoula Valley flank.

Immediately east of the mouth of Butler Creek, McMurtrey et al. (1965) show northeast-dipping Pliocene (?) strata in faulted contact with Oligocene (?) strata (schematically illustrated in Figure 5 and mapped on Plate 1, both of McMurtrey et al., 1965). My study identifies all northeast-tilted strata in this area as conformable and part of the lower Tertiary unit (Plate 1). There is no evidence of faulting. Rather, the boulder-dominated conglomerate facies of the upper Tertiary unit horizontally overlies the lower Tertiary strata (Plate 1). McMurtrey et al. (1965) mistakenly identified the tilted strata as "Pliocene (?)" and failed to recognize horizontally-oriented upper Tertiary strata anywhere on the northeast flank of the Missoula Valley.

According to McMurtrey et al. (1965), a right-lateral oblique normal fault termed the Hourglass Fault runs parallel to the Ninemile Fault through most of the field area and merges with the Ninemile Fault just east of O'Keefe Creek (US93) (Plate 1 of McMurtrey et al., 1965). McMurtrey et al. (1965) provide only vague, geomorphic and topographic evidence of this fault, however, and no evidence of displacement from this fault was found by this study. Thus, the existence of the Hourglass Fault is doubtful, and the fault has not been plotted on the geologic map (Plate 1) of this study.

There are many elongated, level ridges in the field area, and along many of them are topographic depressions or saddles (B 13-19-4c; B 14-19-32d; B 14-19-31b; B 14-20-36b; B 14-20-27a). It is tempting to hypothesize the existence of faults through these saddles, but many of the saddled ridges are at least partially composed of untilted upper Tertiary strata. Where only lower Tertiary strata occurs along the Missoula Valley flank, differential weathering of the northwest-striking strata can account for the alignment of ridge saddles.

4.0 AQUIFER POTENTIAL IN THE LOWER TERTIARY UNIT

I considered the distribution of poorly consolidated conglomerate and associated sandstone in the attempt to define an aquifer within the lower Tertiary strata. The conglomerate found in outcrops east of Grant Creek, colored blue on Plate 1, met this general criteria. These weakly-cemented, coarse beds are widely distributed in the Butler/La Valle Creeks area, contain distinctive clasts of mylonite, and have thin interbeds which display bedding orientation well. The aquifer potential of these conglomerate beds and the ability to target them in the subsurface is shown schematically in Figure 7.

The other conglomerate type, found mostly east of Grant Creek and colored red-brown on Plate 1, is very well cemented and typically does not display bedding orientation; its distribution is difficult to trace through the field area and its cementation has reduced pore space. Consequently, this second conglomerate type was not evaluated for aquifer potential. The coarse upper Tertiary unit was not considered for aquifer potential due to its distribution; it lies above tributary drainages and is above regional ground-water levels.

The outcrop on the east flank of La Valle Creek (B 14-20-24b) provides the best opportunity for the evaluation of aquifer potential. It displays 240 meters of poorly consolidated, mylonite-bearing conglomerate. A thin sandstone interbed shows the unit strikes 134 degrees and dips northeast at 37 degrees. Based on the orientation and the length of the outcrop, the conglomerate is at least 150 meters thick.

Various ground-water wells have been drilled down-dip of this unit in Butler Creek (B 14-20-24a). Logs of these and other wells, in addition to pumping test and well perforation interval data, were obtained from the Montana Bureau of Mines and Geology

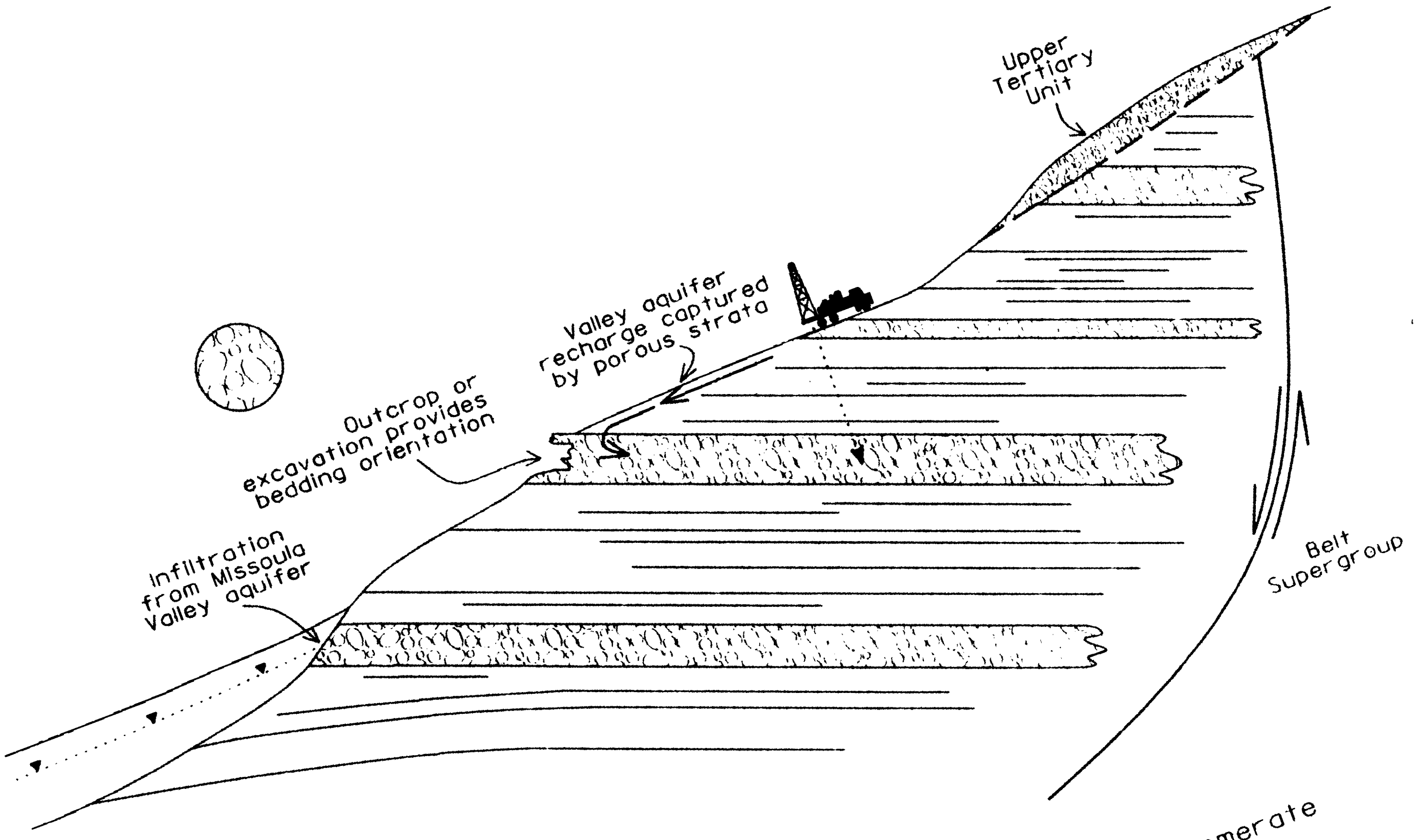

Figure 7: Target-well-drilling of mylonite-bearing conglomerate strata in the lower Tertiary unit

and are included in Appendix 2. Though these logs provide very general lithologic descriptions, the wells commonly encountered "gravel" at depth, along with "coal"," sand", and light brown, grey, and yellow "clay," (descriptors commonly used by drilling contractors drilling through the lower Tertiary unit). But there is no indication of a conglomerate ("gravel") deposit in excess of 100 meters (328 feet) thick.

However, well M:5986 (Appendix 2, pages 2-3) was drilled to 886 meters (2,907 feet) and is the same well drilled as part of the MBMG drilling project which evaluated deep aquifers in the Bitterroot and Missoula Valleys (MBMG open-file report 46 by Norbeck, 1980). Two wells were drilled in the Missoula Valley as part of the project, and well M:5986 (referred to alternately as MB-4 and Well No. 4 in Norbeck, 1980; referred to hereafter in this report as MB-4) was located in the field area of this study. The MBMG open-file report provides a specific location for well MB-4 (B14-20-24adbcb) and graphic, descriptive and geophysical logs of the well. Excerpts of the MBMG open-file report regarding well MB-4 are included in Appendix 3 of this report.

Figure 8 illustrates the spacial relationship between the outcrop of the mylonite-bearing conglomerate along La Valle Creek and the location of well MB-4. Using a fold line oriented in the dip direction, the subsurface projections of the conglomerate bed and the well are schematically shown on the same figure. As illustrated, well MB-4 intersects the conglomerate bed between depths of 412 meters (1,350 feet) bgs and 602 meters (1,975 feet) bgs. This assumes a planar projection of the conglomerate bed.

Also shown on Figure 8 is the correlation of the different logs for MB-4 to the subsurface projection of the conglomerate bed. The graphic lithologic log for well MB-4

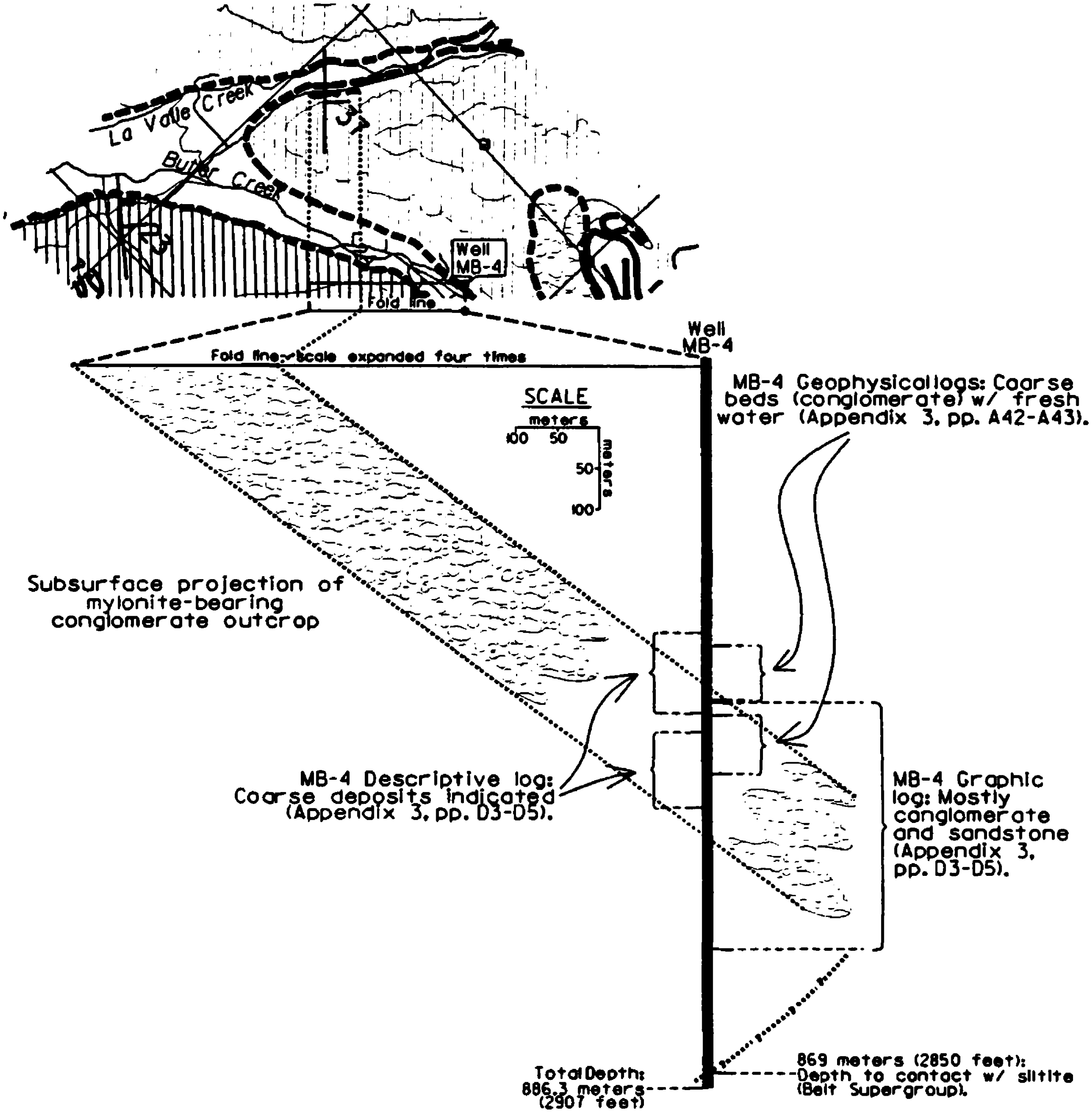

Figure 8: Fold line projection of mylonite-bearing conglomerate bed in lower Tertiary unit

indicates that mostly conglomerate and sandstone were encountered from approximately 420 meters (1380 feet) bgs to 720 meters (2360 feet) bgs (Appendix 3, pages D3-D5). The descriptive lithologic log which accompanies the graphic log is difficult to decipher due to poor reproduction quality and the cryptic abbreviations used by the well logger. However, between 335 meters (1100 feet) bgs and 433 meters (1420 feet) bgs and from 457 meters (1500 feet) bgs to 549 meters (1800 feet) bgs frequent mention of quartz and quartzite clasts is made, indicating a degree of coarseness to the deposit encountered during drilling (Appendix 3, pages D3-D5). An analysis of the spontaneous potential and resistivity geophysical logs for well MB-4 reveals coarse deposits containing fresh water were encountered from approximately 350 meters (1150 feet) bgs to 418 meters (1370 feet) bgs and from 436 meters (1430 feet) bgs to 508 meters (1665 feet) bgs (Appendix 3, pages A42-A43, second and fourth lines of geophysical logs). Taken in whole, the above data largely corroborate the projection of the conglomerate bed, indicating that it may be possible to target this unit in the subsurface.

Geologic mapping was not part of the MBMG aquifer evaluation drilling project, and consequently, correlations between outcrops and subsurface units were not made. In well MB-4, the casing was perforated at a variety of intervals beginning at 197 meters (645.9 feet) bgs, and no perforated interval exceeded 12.5 meters (41 feet). Metal casing was emplaced to 872.9 meters (2,863.1 feet) bgs (Appendix 3, pages B2-B3). According to the graphic and descriptive lithologic logs, siltite, presumably from the Belt Supergroup, was encountered from 869 meters (2850 feet) bgs to the depth of the hole (Appendix 3, page D-5). Static water level in the well measured between 4.1 meters (13.4 feet) bgs on

February 8, 1979, 0.83 meters (2.72 feet) bgs on August 2, 1979, and 7.27 meters (23.84 feet) bgs on September 17, 1979.

Five drawdown tests and three drawdown and recovery tests were conducted on the well to determine aquifer properties. However, a variety of different water-bearing units were tapped by the sporadic perforation of the casing, and no one unit was isolated and tested using packers. The transmissivity values calculated by the tests, therefore, are not representative of isolated units within the Tertiary strata. A pumping test was conducted using a single packer set at 448.2 meters (1470 feet) bgs, but this isolated the upper 448 meters of the well, not an individual hydrostratigraphic unit. The purpose of this packer test is unclear. Probably the testing most representative of the hydrogeologic properties of the strata tapped by various perforated intervals in the well are the drawdown and recovery tests conducted on September 17, 1979 (Appendix 3, pages C33-C36). Using the drawdown data, a transmissivity of 122 gallons per day per foot (gpd/ft) was calculated, and accordingly, approximately the same transmissivity was calculated with recovery data (119 gpd/ft). Transmissivity was calculated using the Jacob straight-line time-drawdown method (Fetter, 1994). The plot of the drawdown data indicate drawdown decreased after the drawdown extended approximately 18 meters (60 feet) below the measured static water level (Appendix 3, page C35). Recovery after drawdown slowed correspondingly after the water level in the well rose approximately 19 meters (62 feet) (Appendix 3, page C-36). The shallowed deflections from the expected drawdown and recovery curves may represent the influence of a subsurface zone of recharge (Fetter, 1994; Driscoll, 1989). Storativity values calculated in Norbeck (1980) and presented with transmissivity data in Appendix 3 should be disregarded; the values were incorrectly calculated using pumping well drawdown data. In aquifer pumping tests, storativity is to be calculated from drawdown data obtained from an observation well proximal to a pumping well (Fetter, 1994).

A transmissivity value of 122 gpd/ft is very low compared to that of Quaternary deposits in the Missoula Valley; Geldon (1979) calculated an average transmissivity of 699,927 gpd/ft for the younger, coarser sediments. The 122 gpd/ft value is also well below Geldon's (1979) averaged transmissivity value of 979 gpd/ft for "Oligocene-Miocene sand and gravel." Nonetheless, the value is significant considering the lowest transmissivity value for Tertiary strata reported by Geldon (1979) was 37.3 gpd/ft and considering that the perforated intervals for well MB-4 probably do not tap all of the most transmissive units of the Tertiary strata penetrated.

The second highest transmissivity value Geldon (1979) reports for "Oligocene-Miocene sand and gravel" is 1,557 gpd/ft. Geldon (1979) calculated this value from pumping testing conducted on a well drilled for public supply by Mountain Water Company of Missoula, Montana in 1972. The well is within the southwest portion of the field area, near the mouth of La Valle Creek (B 14-20-26cccb). MBMG recorded this well as M:132890; its log is in Appendix 2, pages 1-2. Based on the lithologic log and the proximity of the well to outcrops of the lower Tertiary unit (Plate 1), it is apparent the well was drilled within the lower Tertiary unit.

The well was drilled to a depth of 114.3 meters (375 feet) bgs, but it was perforated only in one short interval, from 42.1 meters (138 feet) bgs to 43 meters (141 feet) bgs

(Appendix 2, page 7). The lithology for this interval reads, "Gravel sand and water," the interval is confined top and bottom by clay-rich layers (Appendix 2, page 2).

Obviously, this thin water-bearing zone was targeted during well installation based on the lithology recorded during drilling. Currently, the production of the well is significant enough to be maintained for public supply by Mountain Water Company. Water is pumped from the well at a rate of 25 gallons per minute (gpm) (Lukasik, 1997). The water-bearing strata cannot be correlated with outcrops of the northerly-dipping lower Tertiary unit because it was encountered in the subsurface, to the south of the closest outcrop. But it is nonetheless indicative of the potential productivity of similar strata within the lower Tertiary unit.

5.0 LANDSLIDES AND LANDSLIDE POTENTIAL

5.1 OBSERVED LANDSLIDES

Many Quaternary landslides were geomorphically recognized in the field area. Most are relatively ancient; the landslide toes blend subtlety with adjacent topography, and the landslides lack sharp, defined head scarps. Larger landslides are most easily recognized by the hummocky topography of the landslide mass (B 14-19-19, B 14-20-13). Also, the larger slides generally extend to canyon drainages. Some of these slides have altered the drainages, causing the stream beds to deviate around the toes of the landslides (B 14-20-13b and B 14-19-19b). But the largest landslide in the field area, on the east side of Butler Creek (B 14-19-19c), has not altered the creek bed; conversely, stream erosion has removed the landslide toe. This difference may reflect the relative speed of landslide slippage. A landslide, emplaced downslope as a creeping mass, would, upon reaching the canyon drainage, have its toe eroded by stream action as a result of the slow encroachment of the slide. But a landslide moving with comparatively greater speed would overwhelm the canyon drainage, clogging the existing stream bed and possibly causing the temporary blockage of the drainage. The stream would abandon the channel and be diverted around the toe of the landslide.

The majority of landslides, including the largest landslide, were observed in the Butler and La Valle Creek drainages, just southwest of the Ninemile Fault trace (Plate 1). Most of the other slides were also in the southwest vicinity of the Ninemile Fault. Some of these smaller slides were associated with springs (B 14-19-33d, B 14-19-28c, B 14-20-13b). Springs and ponds were observed within the two largest landslide masses (B 14-19-19c, B14-20-13a and d). Based on the arcuate outline of all the landslides, I infer that the landslide failure surfaces are spheroidal, as opposed to planar.

I observed one active landslide in the field area. The landslide is on the east flank of Grant Creek, near the mouth of the creek (B 13-20-5b) (Figure 9). It was determined to be active because the toe of the landslide was clearly defined, and its encroachment onto the Grant Creek alluvial plain was marked by the tilting of fence posts (Figure 10). Also, its head scarp was sharply defined, and a narrow graben was observed between the head scarp and the top of the slide. The landslide occurs within the limits of a larger, inactive landslide (Figure 11).

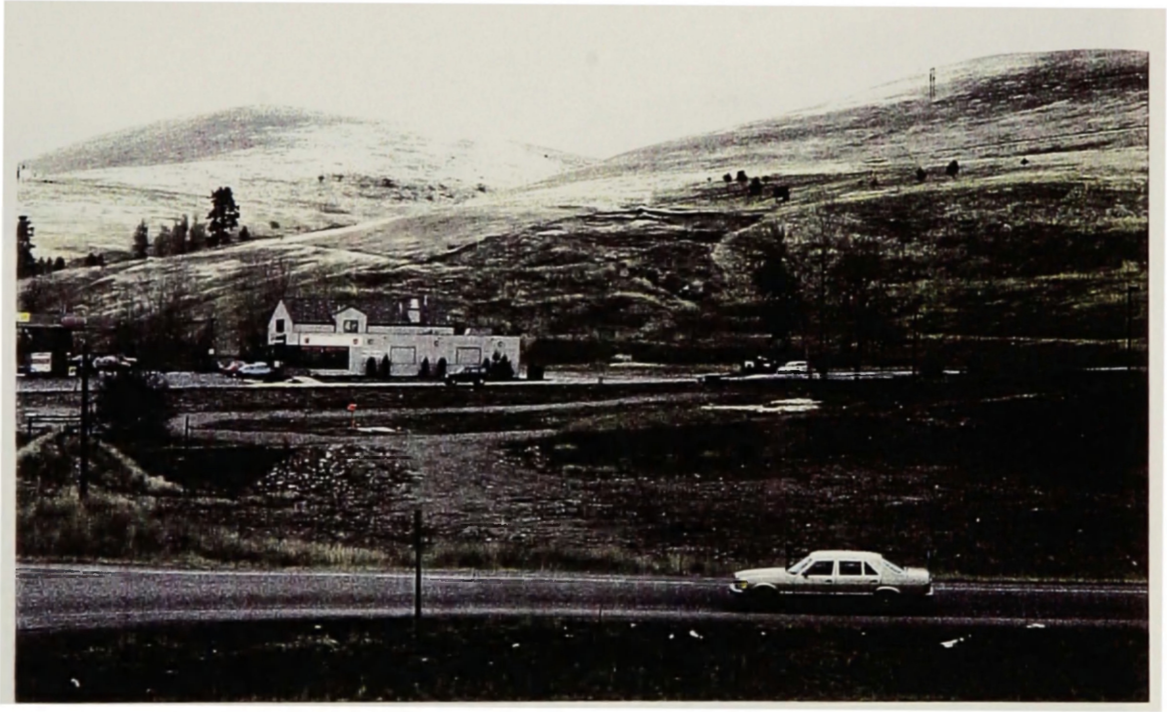

Figure 9: Active landslide on east flank of Grant Creek

Figure 10: Toe of active landslide

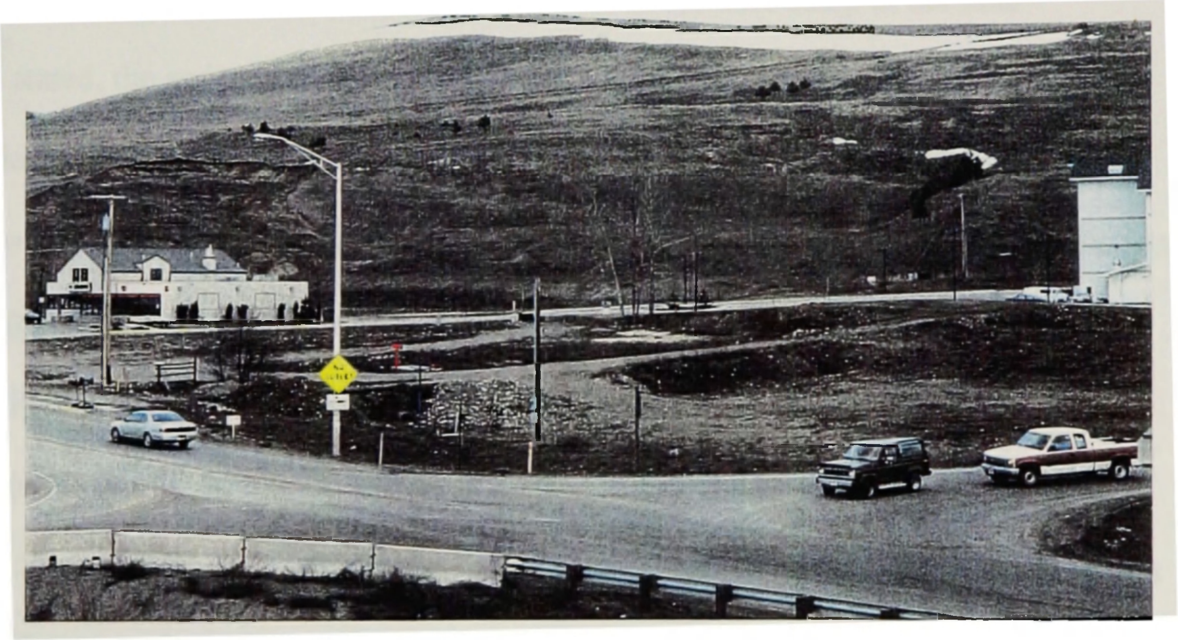

Figure 11: Inactive landslide. Tree groupings mark approximate limits of inactive landslide; active landslide is on left side of photograph.

5.2 LANDSLIDE POTENTIAL

In all but two landslides, slippage clearly involves the lower Tertiary unit. The other two landslides (B 13-19-10c and B 14-19-33d) may involve failure of the lower Tertiary unit, but this cannot be surficially deciphered due to concealment by the upper Tertiary unit. In most cases the upper Tertiary unit appears adjunctly related to landsliding.

The active landslide east of Grant Creek (B 13-19-5b) provides the best opportunity for study of a typical landslide in the field area. Failure occurs within the lower Tertiary unit, but the upper Tertiary unit is upslope and adjacent to the head scarp of the slide.

As stated, the active landslide occurs within a larger inactive slide (Figure 11). The material exposed in the head scarp of the active landslide consists of landslide debris generated from the larger, older slippage of the lower Tertiary unit. The lithology consists of mostly massive sandy siltstone that is yellow brown, moist to very moist, and poorly consolidated. Single pebble and cobble clasts of quartzite and argillite are found sporadically within the matrix. Remnant bedding within the siltstone is rare, discontinuous, and contorted. Cobbles and boulders, though widely separated, are strewn on slopes above the active landslide. The slide mass is broken and partially eroded; the failure surface(s) is exposed at several locations within the landslide. Failure surface exposures are striated, marking the downslope motion of the displaced mass, and are brown and grey and clayey. At one exposure a striated, lignitic coal stringer marks the surface of landslide motion (Figure 12).

The cause of the landslide is not related to the orientation of the lower Tertiary unit. On the same slope as the landslide, in a road cut south of the landslide area, in-place strata

Figure 12: Exposure of landslide failure surface. Note desiccation cracks indicating previously moist, expansive clay; lignite stringer has been smeared along failure surface.

strike north-northwest and dip 15 degrees east-northeast, into the slope. The slope on which the landslide occurs is inclined to the west-southwest at approximately 20 degrees.

The landslide failure is instead related to the incompetency of certain strata within the lower Tertiary unit, specifically the ash-rich claystones, mudstones and siltstones found throughout much of the unit. Outcrops of this strata are colored dark grey on Plate 1. The failure surface exposures within the landslide are clay-rich, and lignitic coal, common within the ash-rich beds, is seen on one of the failure surface exposures. The lithologies exposed within the landslide and in the head scarp are not exclusively the ash-rich, fine-grained deposits; the landslide debris incorporated some strata upslope, upsection, from the fined-grained incompetent beds on which movement initiated.

The head scarp above the active landslide was very moist in places. Free water was observed in one area. Clearly, water provided weight and lubrication to the slide mass. It may also have sped the diagenesis of ash to smectitic clay, creating a differential of competency along the strike of tuffaceous units.

The water is from the overlying upper Tertiary unit. The unit is immediately upslope from the landslide (Plate 1). This facies of the upper Tertiary unit is very coarse grained and poorly consolidated, composed mostly of gravel and boulders; the gravel pit excavation exposing over 35 vertical meters of unit is approximately 600 meters to the northeast of the active landslide (Plate 1).

It seems unlikely that incompetent ash-rich strata striking along slopes of 20 degrees or more is the sole cause of landslide failure. Otherwise, the number of landslides on the northeast flank of the Missoula Valley would be far greater. Rather, it is likely that the mechanism causing the landslide failure is due to the interaction between the upper Tertiary unit, fine-grained deposits of the lower Tertiary unit, and water that migrates along the contact between the two units. The interstitial water within the upper Tertiary unit migrates downward rapidly, relative to the lower Tertiary unit, because the upper unit is much more coarse and contains few fines. The water, upon reaching the slightly inclined contact with the lower Tertiary unit, migrates along the contact, slowly infiltrating and, at times, saturating the lower unit. The fine-grained, ash-rich deposits of the lower Tertiary unit are poorly lithified, inherently weaker and capable of retaining much more water than other beds within the unit. The water would lubricate, add weight, and decrease the cohesion of grains within the ash-rich strata. Near the topographic surface, where the water-logged contact intersects with ash-rich, fine-grained beds of the lower Tertiary unit, landslide failure may occur if the topography along the contact is sufficiently steep. Additionally, the overburden of boulders and gravel from the upper Tertiary unit would further increase the landslide potential by adding to the downward driving forces necessary for slippage. This interaction is shown schematically in Figures 13 and 14

The active landslide occurs within a larger inactive slide. The weathered and brush-covered scarp of the larger slide extends upslope, beyond the contact between the two Tertiary units, into the upper unit. Similarly, many of the other landslides in the field area straddle this contact, partially incorporating the upper Tertiary unit (Plate 1). Based on the example provided by the active landslide, I postulate that the mechanism that triggered these landslides is the same as the one causing the active landslide.

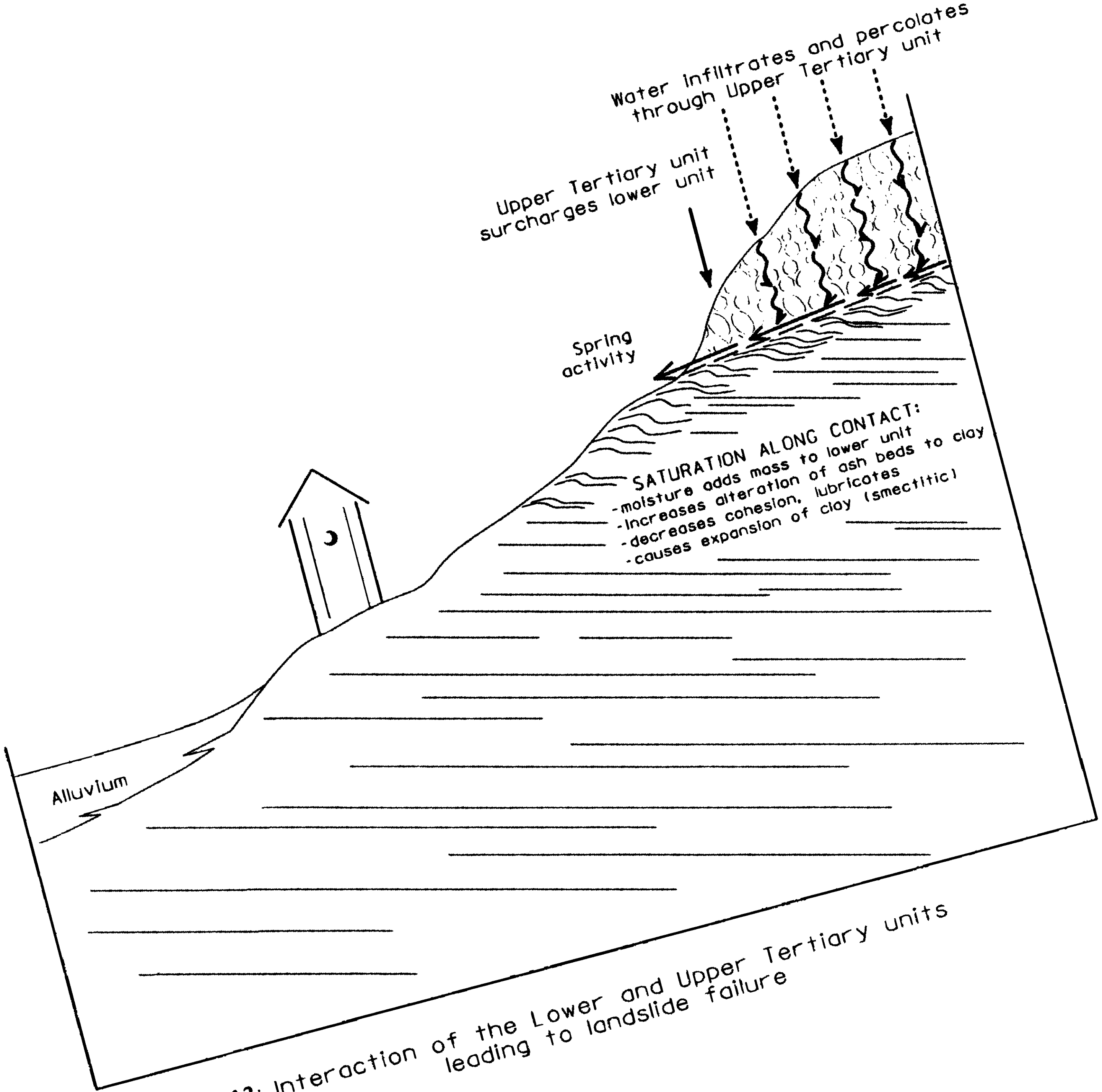

Figure 13: Interaction of the Lower and Upper Tertiary units leading to landslide failure

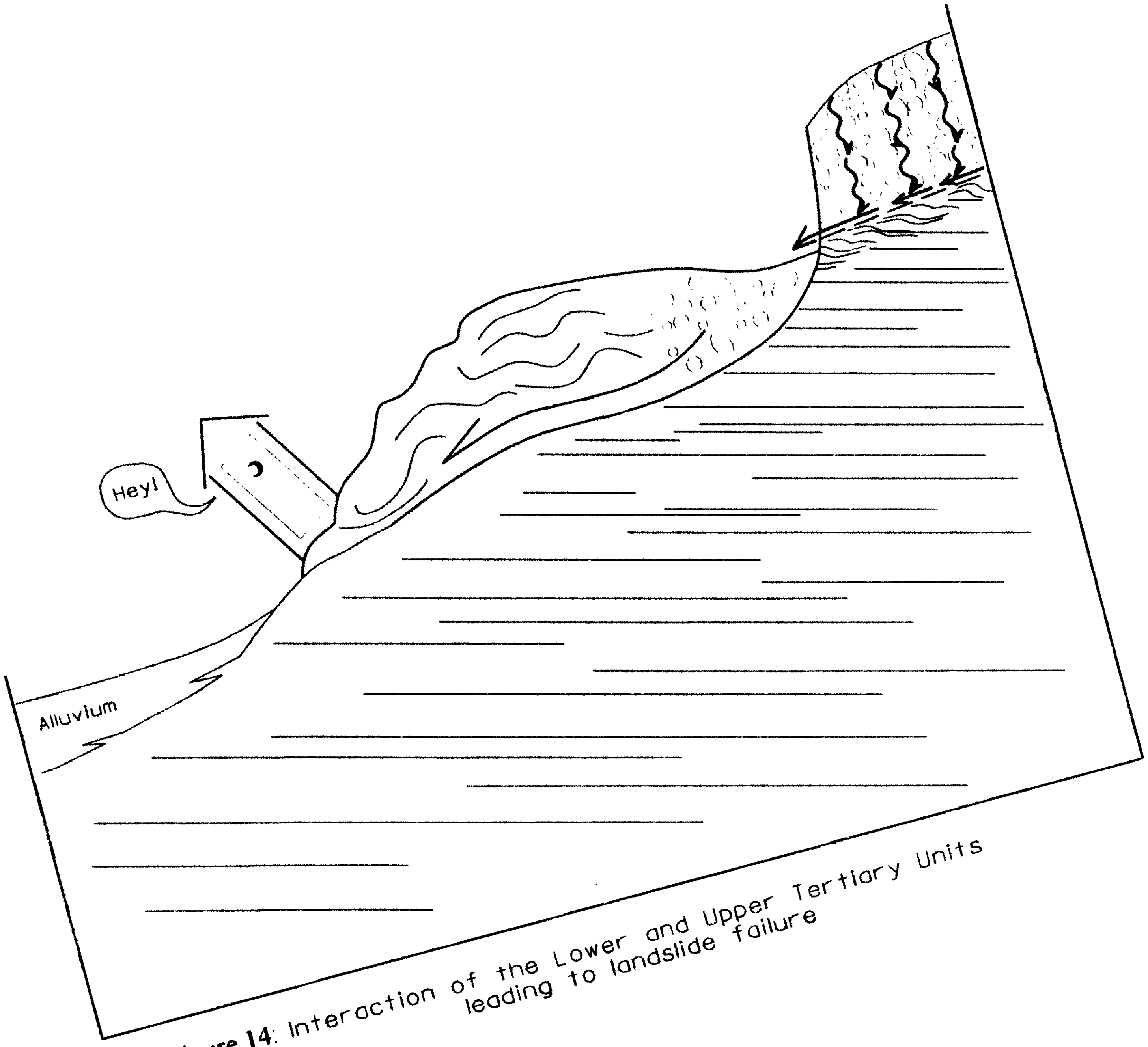

Figure 14: Interaction of the Lower and Upper Tertiary Units leading to landslide failure

Except for water dripping from the head scarp above the active landslide, springs were not encountered along the contact between the upper and lower Tertiary units. However, phreatophytic plants commonly straddle the contact, indicating a near-surface, relatively plentiful source of water.

Landslide potential within the field area is high for slopes that are capped by the upper Tertiary unit. As demonstrated by the active landslide, failure may occur where slope inclination is 20 degrees or less.

The largest landslides in the field area occur in the southwest vicinity of the Ninemile Fault trace (Plate 1). This is probably due to greater deformation and weakening of the lower Tertiary unit where it is in close proximity to the Ninemile Fault. Several springs, presumably related to the faulting, are also found in this region. Consequently, landslide potential is high near the Ninemile Fault trace.

Orientation of the lower Tertiary strata does not appear to be a factor of landsliding in the field area, primarily because the regional dip of the strata is to the northeast, into the valley flank topography. But several small drainages feeding the larger tributaries have flanks that face the northeast. It is possible that downcutting in these drainages has removed buttressing support of northeast-dipping bedding, creating the potential for block or planar type landslide failure. However, evidence of this type of landslide failure was not found in the field area.

Finally, the potential for the reactivation of a landslide exists when the toe of a landslide is removed because the resisting forces that stabilized the slide mass are reduced. A small, ephemeral stream channel breaks from the main channel of Grant Creek and runs near the toe of the active landslide (B 13-19-5b). Stream erosion from this channel may have removed a portion of the toe of the larger inactive landslide, preferentially determining the location of the active slide. Additionally, various grading activities to level the area below the landslide may have exacerbated landslide potential. The toe of the largest landslide in the field area (B 14-19-19c) has been removed by stream erosion from La Valle Creek. But recent movement of this landslide was not detected by this investigation, and the landslide is considered inactive.

5.3 ADDENDUM: RENEWED LANDSLIDE MOVEMENT OBSERVED

I revisited the active landslide east of Grant Creek (B 13-19-5b) on March 28, 1997. The head scarp of the landslide had migrated approximately five meters upslope and the landslide had formed a two new lobes that were encroaching onto the Grant Creek alluvial plain. Various small depressions within the slide mass contained ponded water, and water was flowing slowly through earth materials at the base of the head scarp. Phreatophytic plants were growing at the base of the head scarp.

Southeast of the landslide, along the approximated contact between the upper and lower Tertiary units, was a spring and numerous phreatophytes; slumping of earth materials had occurred adjacent to and downslope from the spring. Reconnaissance of the ancient landslide in which the active landslide occurs revealed cracking in the earth surface up to 3 cm wide and small scarps subparallel to the contour of the hillside which show downdropped displacement of 5 to 10 centimeters. The evidence of renewed movement was observed along the hillside southeast and adjacent to the active landslide and upslope from the active landslide, to the top of the ancient landslide.

The renewed movement is undeniably related to an increase in water flowing though the upper Tertiary unit. The water has been generated from melting snow and Spring rains which infiltrate the upper Tertiary unit. The additional water enables more of the underlying lower Tertiary unit to become saturated and prone to failure. Renewed movement probably occurs annually each Spring, but the amount of movement is dependent on snowpack and precipitation.

6.0 DEPOSITIONAL INTERPRETATION

6.1 LOWER TERTIARY UNIT

The lower Tertiary unit I mapped on the northeast flank of the Missoula Valley should be considered formationally distinct from the Renova Formation and should only be compared to the Renova Formation on a time-equivalent basis. The fine-grained deposits within the lower Tertiary strata are similar to the siltstone, mudstone, coal, and reworked deposits of ash that typify the Renova Formation in southwest Montana. However, the conglomerates found within the lower Tertiary unit set the unit apart from the Renova Formation.

Conglomerate within the Renova Formation is considered a minor constituent (Kuenzi and Fields, 1971; Fields et al., 1985). The conglomerate units at the BFI landfill comprise well over 50% of the total exposure (Plate 2 and Appendix 1), and outcrops of conglomerate account for about 50% of the lower Tertiary exposures elsewhere in the field area. This indicates the conglomerate is at least a significant component of lower Tertiary unit and therefore lithologically distinct from the type Renova Formation.

The fluvial origin of mylonite-bearing conglomerate further distinguishes the lower Tertiary unit from the locally-derived coarse clastic and fine-grained, ash-rich deposits (Fields et al., 1985) of the Renova Formation. The distinctive mylonite clasts were derived from the mylonite zone in the Bitterroot Mountains, west of the Bitterroot Valley. Pebble to cobble-sized clasts of this rock found in conglomerate outcrops west of Grant Creek indicate that a fluvial system of a size comparable to the present Bitterroot River flowed due north from the Bitterroot Valley. The broad range over which this conglomerate type is found, from approximately 1.2 km west of Butler Creek (B 14-20-36b) to O'Keefe Creek (US93) (B 14-20-15b), indicates that the river aggraded within a broad valley. The river system probably continued north of O'Keefe Creek (US93), but normal movement on the Ninemile Fault has almost certainly led to the erosion and obliteration of Tertiary strata on the footwall block.

Janecke (1994) proposes that the ash-rich Renova Formation originated in a north-trending, Eocene to Oligocene rift zone but that the sediments were transported east from the rift zone, down the rift shoulder to a broad, quiescent lowland in southwest Montana. Her model fits the depositional interpretations of others who claim the Renova Formation accumulated in a large, regional basin (Kuenzi and Fields, 1968; McDowell and Fritz, 1993; Fritz and Sears, 1993). A provenance and paleocurrent study of Paleogene deposits (Renova Formation) in southwest Montana provides further evidence for Janecke's model (Thomas, 1995).

Janecke (1994) also theorizes that rivers may have flowed north within the rift zone, transporting and depositing sediment of a lithology similar to the Renova Formation (Figure 15). Though compositionally similar to the Renova Formation, these strata would be distinct because the depositional system would be a rift valley, as opposed to a rift shoulder and adjacent basin.

Janecke's (1994) proposed rift zone trends north and includes the Bitterroot and Missoula Valleys. The mylonite-bearing conglomerate observed in this study lends credence to such a fluvial system confined within a rift valley.

In a meandering or a braided fluvial depositional system, channel abandonment and overbank deposition would be common, particularly during the Eocene when volcanism peaked in the region (Chadwick, 1985) and prodigious amounts of ash clogged drainages. Various paludal environments would develop adjacent to the drainage, allowing for the accumulation of fine-grained, ash-rich sediments and carbonaceous material. The resulting light-colored, fine-grained strata and thin coal interbeds seen in the field area would therefore resemble the Renova Formation seen in southwest Montana.

The eastern edge of the north-flowing fluvial environment probably runs beneath the hills that are west of Grant Creek because mylonite-bearing conglomerate is not found east of these hills. East of Grant Creek ash-rich strata, lenticular conglomerate beds, and sandstone are exposed in outcrops and at the BFI landfill. These deposits were probably derived from a series of broad, gently inclined, coalescing alluvial fans that would have flanked a broad, north-draining river valley.

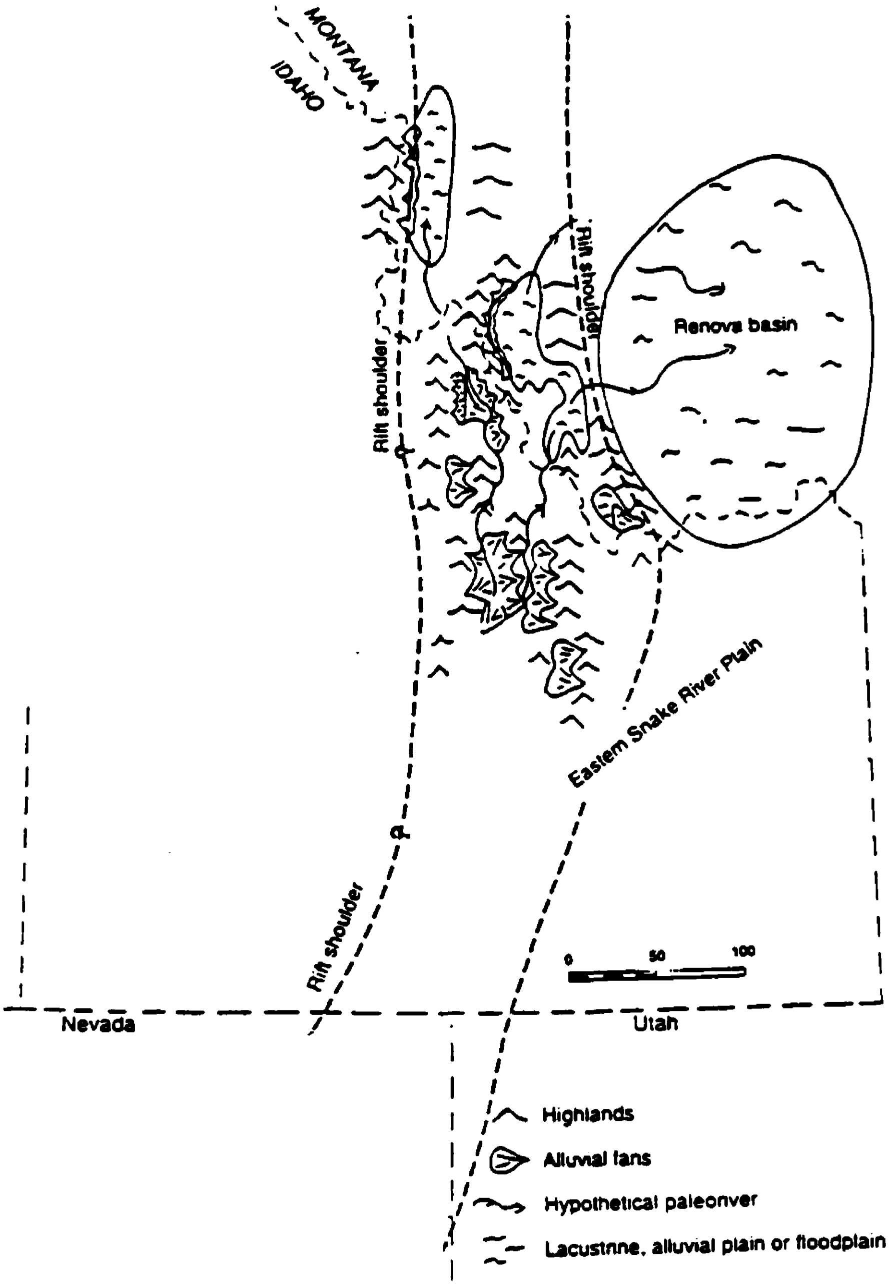

Figure 15: Fluvial deposition from north-flowing river systems within a proposed Eocene to Oligocene rift zone coeval with deposition of the basinal Renova Formation (from Janecke, 1994)

6.2 UPPER TERTIARY UNIT

At the BFI landfill, the conglomerate facies of the upper Tertiary unit is horizontal and unconformably overlies the lower Tertiary unit. It is a fluvial channel deposit; a portion of a broad river bed is delineated by the basal conglomerate of the facies (Figure 3). The channel bank can also be deciphered, though this has been obscured by sloughing from grading activities at the landfill. Imbrication indicating a north to northwest-directed flow direction can be observed at a distance.

The exposure at the BFI landfill was the only clearly viewed outcrop of the conglomerate facies of the upper Tertiary unit. East of the landfill I encountered gravel in small road cuts and gravel float on slopes and through a topographic saddle (Plate 1). I interpret these rocks as part of the same conglomerate facies.

The river system indicated by the conglomerate facies may be ancestrally related to the Clark Fork River. It probably flowed northwest, along the northeast margin of the Missoula Valley floor. The valley floor would be lowest along its northeast margin due to normal downdropping on the Ninemile Fault. Fault movement would have ceased (as indicated by the horizontal orientation of the conglomerate facies), but drainage of the valley probably had been well established by the valley-floor downdropping and would remain established along northeast margin for a time after fault movement ceased. Much later, in the Quaternary, subsequent erosion from the faulted margin and progradation of the northeast Missoula Valley flank would push valley drainage southwestward to its present location along the southwest and west margins of the valley.

Other occurrences of the conglomerate facies of the upper Tertiary unit unconformably overlying the lower Tertiary unit are seen on the valley flank in road cuts northwest of the field area. The conglomerate facies probably lies elsewhere in the field area, but it has likely been concealed by concurrent deposition of the boulder-dominated conglomerate facies of the upper Tertiary unit.

I interpret the boulder-dominated conglomerate facies as remnants of a broad debris-flow/alluvial fan system which flowed primarily out of an ancestral Grant Creek. Great amounts of material were generated from uplands north of the field area, uplands presently known as the Jocko/Rattlesnake Mountains. The mountains, having been recently uplifted by the Ninemile Fault, had greater relief than today. The greater relief provided the potential energy needed to transport boulder-sized clasts and other coarse deposits to their present location in the field area. The coarse clastic material was probably transported within a thick slurry of mud generated from the upland erosion of ash-laden deposits related to the lower Tertiary unit or the Renova Formation. Large amounts of air-fall ash from Cascade volcanism may have also blanketed the slopes (Chadwick, 1985), adding to the mud matrix. Subsequent to the deposition of the boulder-dominated conglomerate, winnowing of the fine-grained fraction of the deposit by overland water flow would leave the coarse-grained fraction of the deposit strewn on the slopes of the valley flank (see Blair and McPherson, 1992).

The distribution of the boulder-dominated conglomerate facies indicates the debris-flow/alluvial fan system originated from an ancestral Grant Creek. On the west flank of Grant Creek, the basal contact of the boulder-dominated conglomerate facies indicates that the Grant Creek alluvial plain had been 70 meters (200 feet) to 90 meters (300 feet) above the present creek bed.

The Butler and La Valle Creek drainages are smaller than the Grant Creek drainage. They were probably not well developed when the boulder-dominated conglomerate facies from Grant Creek was deposited, though they may have been ancillary to the Grant Creek fan system. Consequently, significant deposits of the facies are not seen west of Butler Creek (Plate 1).

Rattlesnake Creek is much larger than Grant Creek and certainly would have been capable of generating a debris flow/alluvial fan facies comparable to that of Grant Creek. Yet I found no record of such a depositional system along the flanks of Rattlesnake Creek. I surmise that such a system did exist but that erosion and downcutting by the concurrent river facies removed record of an upper Tertiary Rattlesnake Creek alluvial system. Pliocene erosion and pediment formation may have aided the removal.

7.0 CONCLUSIONS

The two Tertiary units which occur on the northeast flank of the Missoula Valley are distinct from each other and should be mapped separately. Vegetation and Quaternary cover make mapping difficult, but depositional interpretations aid in understanding the distribution and lithology of each unit.

The lower Tertiary unit is a broad river valley deposit dating from the Eocene. The river system aggraded as it flowed north from an ancestral Bitterroot Valley. The river probably continued north of O'Keefe Creek (US93), but later normal movement on the

Ninemile Fault diverted the river to the northwest and led to erosion of the unit on the footwall block. Overbank deposition and channel abandonment were common creating paludal environments adjacent to the river channel; fine-grained sediments, including abundant ash from regional volcanism, and carbonaceous material accumulated in the marshy areas. The meandering, north-flowing river system was flanked on the east by broad, gently inclined coalescing alluvial fans. The lower Tertiary unit is distinct from the Renova Formation because it contains significant amounts of coarse clastic material, much of which was derived from remote locations to the south.

Middle Miocene regional faulting signaled the onset of Basin and Range extension. The Ninemile Fault dropped the valley floor and raised the Jocko/Rattlesnake Mountains. The lower Tertiary unit was tilted to the northeast, deposition ceased and erosion ensued.

By the middle Miocene, deposition of the upper Tertiary unit began. Due to the recent fault uplift the depositional environment was highly energetic. Mud and boulder-laden debris flows coursed from young, steep valleys of the Jocko/Rattlesnake Mountains while a strong perennial river developed and flowed northwest, along the flanks of developing alluvial fans. The river may be ancestrally related to the Clark Fork River. Based on the lithology, depositional environment, and chronostratigraphy relative to Quaternary deposits and the lower Tertiary unit, the upper Tertiary unit is related to the Sixmile Creek Formation, although a lack of age control within the unit makes its designation as part of the Sixmile Creek Formation premature.

With an understanding of the distribution and depositional environment of the lower Tertiary unit, fluvial conglomerate beds can be identified. These beds are capable of transmitting significant quantities of water to wells. With accurate attitude readings of a conglomerate, a subsurface projection of the bed can be made and the unit can be targeted for well drilling.

Nearly all the landslides on the northeast flank of the Missoula Valley result from the interplay of the lower and upper Tertiary units. Interstitial water drains through the upper Tertiary unit and travels along the contact between the upper and lower units. Near the topographic surface, where the water-logged contact intersects with ash-rich, fine-grained beds of the lower Tertiary unit, landslide failure may occur if the topography along the contact is sufficiently steep. The poorly lithified, clayey, ash-rich beds within the lower Tertiary unit become more incompetent when saturated with water. Overburden from the upper Tertiary unit adds to the driving forces necessary for slippage. A reasonable estimate of landslide potential can be made based on proximity to the geologic contact between the upper and lower Tertiary units.

The computer version of the geologic map (Plate 1) is on file with the Geology Department of the University of Montana. The computer version is meant to be a dynamic geologic map. Exposures of the two Tertiary units are rare, but various excavations made perpetually throughout the valley flank provide additional glimpses of the two units. The excavations are typically related to development and therefore the Tertiary exposures are temporary. But as the exposures are made the geologic map can be updated with the new information. Consequently, understanding of the Tertiary stratigraphy on the northeast flank of the Missoula Valley will be continually, quickly, and easily refined.

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APPENDIX 1

Lithology Exposed at the BFI Landfill Cell Excavation
(to be used with Plate 2)

Lower Tertiary Unit:

Deposit 1: Sandstone, mostly light grey-brown, also faintly orange-brown to light brown, fine to medium-grained, poorly to moderately cemented, coarser beds are micaceous (muscovite), occasional siltstone interbeds (<1cm); sandstone grains include quartz, plagioclase, lithics.
Thickness: >14 meters

Deposit 2: Sandstone with pebble conglomerate lenses, alternates very light brown to grey-brown to faintly orange-brown. Sandstone is fine to coarse-grained, weakly to moderately cemented although may be locally very well cemented.
Thickness: 6.5 meters.

Deposit 3: Conglomerate, grey-brown to faintly reddish grey-brown, clast-supported, most clasts are <6 cm in diameter though some are to 15 cm; clasts are subrounded and include quartzites (pink, red-purple, light grey) and argillites (green, grey, red-purple).
Thickness: 11 meters.

Deposit 4: Sandstone w/ some pebble conglomerate lenses, sandstone is light grey-brown, yellow-brown, and light brown and red -brown (from lateritic-staining), fine-grained, moderately cemented; conglomerate lenses are clast-supported and contain subrounded clasts of argillites (green, red-purple, grey, light brown) and quartzites (grey, light grey).
Thickness: 5.5 meters.

Deposit 5: Conglomerate: reddish grey-brown, clast-supported, clasts are subangular to rounded pebbles and cobbles and include quartzites (grey, red, green, brown, white, light brown), argillites (green, greenish grey, grey, red-purple), and shale (light brown); locally well cemented with calcium carbonate; contains some grey-brown, fine to medium-grained sandstone lenses.
Thickness: 7 meters.

Deposit 6: Conglomerate: grey-brown to reddish grey-brown, clast-supported, most clasts are <6 cm in diameter, some larger clasts to 20 cm; clasts are mostly subrounded, some subangular, and include quartzite (red-purple, pink, grey, green), argillites (green, red-purple, grey, light brown), shale (light brown, grey), coarse-grained sand matrix; locally well-cemented with calcium carbonate. Conglomerate fines to a fine-grained sandstone that is pale yellow-brown to light grey brown.
Thickness: 12.5 meters

Deposit 7: Ash Tephra, light grey to white, contains 2 cm thick coal seam.

Thickness variation: 1.5 to 3 meters.

Deposit 8: Conglomerate: pale reddish-brown (lower half) and grey-brown (upper half), clast-supported, most clasts <11cm in diameter, some larger clasts to 40 cm; clasts are mostly subrounded and include quartzites (pink, green-grey, grey, brown), siltstone (yellow-brown), and rare, very weathered and well rounded granitic clasts; matrix is medium to coarse-grained sand that is red-brown (lower half) and pale greenish grey (upper half); locally well-cemented with calcium carbonate. Faint northwest-directed imbrication is indicated by some clast groupings. Conglomerate fines to approximately 2 meters of sandstone and siltstone.
Thickness variation: 18 (?) to 33.5 meters.

Deposit 9: Conglomerate: pale orange-brown to dark yellow brown, clast-supported, most clasts are <10 cm in diameter with many pebbles to 1 cm in diameter, some larger clasts to 30 cm; clasts are subrounded and include quartzites (red, grey, pink, white), argillites (red-purple, green), shale (pale yellow brown and split along remnant bedding), and rare granitics (weathered, plagioclase and quartz-rich); well cemented with calcium carbonate along base of deposit. Conglomerate fines to approximately 2 meters of fine-grained sandstone.
Thickness variation: 6.5 to 9 meters.

Deposit 10: Pebble conglomerate/breccia, grey, matrix-supported (grey silty sand matrix), clasts are <4 cm in diameter, clasts include quartzite, argillite, granite, diabase (?--dark, fine crystalline grained); above base pebble conglomerate/breccia are repeating beds of pebble conglomerate fining to fine-grained sandstone.
Thickness variation: 3.5 to 26.5 meters.

Deposit 11: Interbedded siltstone, sandstone and pebble conglomerates, overall color is red-brown (lateritic) though some beds are light grey. Conglomerates are typically less that one half meter thick, conglomerate clasts include argillites, quartzites. Some thicker conglomerate beds are very well cemented with calcium carbonate.
Thickness: 12 meters.

Deposit 12: Conglomerate, orange-brown, clast-supported, clasts are <5 cm in diameter, most <2 cm; clasts are subrounded and include argillite (red-purple, grey), quartzite (grey, red-purple), granite (rare, very weathered).
Thickness: 13.5 meters.

Deposit 13: Siltstone with pebble conglomerate lenses, light grey to light brown; pebble conglomerate lenses are one half to one meter in width, clast-supported, moderately well cemented; clasts included quartzites and argillites.
Thickness: 9 meters.

Deposit 14: Conglomerate, light brown, clast-supported, clasts are subangular to subrounded pebbles and cobbles and include argillites (grey, light brown, green, red-purple), quartzites (light grey, pink).
Thickness: 9 meters.

Deposit 15: Siltstone with pebble conglomerate lenses, very light grey to light brown, tuffaceous; conglomerate lenses are clast-supported, some cemented with calcium carbonate.
Thickness: 4.5 meters.

Deposit 16: Interbedded sandstone, pebble conglomerate and breccia beds, light brown to very light grey-brown, though some tuffaceous breccia beds are light purple; some conglomerates are locally cemented with calcium carbonate.
Thickness: 26.5 meters.

Deposit 17: Silty sandstone, white, tuffaceous; informally dubbed "the White Beds;" lower half contains lenses of pebble conglomerate and tuffaceous breccia.
Thickness: 10 meters.

Upper Tertiary Unit: Basal cobble conglomerate up to 2 meters thick fining upward to a sandstone and then is followed by a series of pebble conglomerates, sandstones and siltstones. Each bed within the unit is conformable with overlying and underlying beds, and the unit is horizontal. Horizontally-lying basal cobble conglomerate is grey and lies in an approximate 20-degree angular unconformity with the northeast-dipping lower Tertiary unit. The cobble conglomerate is poorly cemented, clast-supported, and has clasts to 60 cm in diameter. Clasts are subrounded and include quartzite (red, white, grey, and grey with pit marks) and some mafic igneous rocks. Faint imbrication indicates estimated flow vector to the northwest. Overlying pebble conglomerates, sandstones and siltstones are light brown to red-brown.
Thickness: >12 meters.

APPENDIX 2

LITHOLOGY	LOCATION...........	SITE.NAME.....................	FROM (FT)	TO (FT).	DESC..
M:120804	14N 20W 27 CCC 01	RYS-SIKORA ADAM/ANNE	0	72	CLAY
			72	90	CLAY AND SAND
			90	93	SAND- GRAVEL- CLAY AND WATER
			93	105	CLAY- SAND AND GRAVEL
			105	106	SAND- GRAVEL AND WATER
M:122227	14N 20W 24 AB 01	INABNIT ELDON	0	12	SAND- CLAY- GRAVEL
			12	35	SAND- CLAY
			35	48	BROWN CLAY- GRAVEL
			48	100	GRAY SHALE- COAL
			100	120	SHALE
M:122231	14N 20W 24 AD 01	INABNIT ELDON	0	16	CLAY- GRAVEL
			16	34	CLAY- GRAVEL
			34	53	SHALE- GRAVEL
			53	70	CONGLOMERATE ROCK
			70	130	SHALE- COAL
			130	137	CONGLOMERATE ROCK
			137	140	SHALE
M:131022	14N 20W 24 ADD 01	TAG RICHARD & PHYLLIS	0	5	TOPSOIL
			5	45	GRAVEL AND CLAY (WATER SATURATED)
			45	53	SAND- GRAVEL- CLAY & WATER (1 TO 2 GPM)
			53	53.5	SAND- GRAVEL AND MORE WATER
			53.5	70	CLAY- SAND & GRAVEL (NO WATER) HOLE BELOW 53.5'
			53.5	70	CAVED IN
M:132334	14N 20W 24 01	SORENSEN BOB	0	53	CLAY
			53	116	CLAY- GRAVEL
			116	130	GRAVEL
M:132890	14N 20W 26 CCCB 01	MOUNTAIN WATER COMPANY * WELL 26	0	5	COBBLESTONES- GRAVEL & TAN CLAY
			5	31	TAN CLAY
			31	39	TAN CLAY AND GRAVEL
			39	68	BROWN CLAY AND GRAVEL
			68	84	LT BROWN CLAY & GRAVEL
			84	85	CLAY GRAVEL & WATER
			85	98	YELLOW CLAY AND GRAVEL
			98	110	TAN CLAY
			110	122	TAN CLAY AND GRAVEL

			122	123	GRAVEL- CLAY AND WATER
			123	132	YELLOW CLAY
			132	138	TAN CLAY SOME GRAVEL
			138	141	GRAVEL SAND AND WATER
			141	150	YELLOW CLAY AND GRAVEL
			150	151	SAND GRAVEL- WATER AND SILT
			151	169	SAND CLAY AND GRAVEL
			169	171	SAND SOME GRAVEL AND WATER
			171	187	SANDY YELLOW CLAY
			187	246	BROWN CLAY
			246	257	BLUE AND TAN CLAY- SOME GRAVEL
			257	272	BLUE CLAY
			272	285	GREEN CLAY
			285	305	BLUE CLAY
			305	350	GRAY CLAY AND GRAVEL
			350	375	GRAY CLAY
M:134866	14N 20W 24 ADB 01	INABNIT STEVEN	0	2	SOIL; ROCK CHUNKS
			2	19	CLAY; ROCK
			19	25	CLAY; GRAVEL (SEEPAGE)
			25	45	BLUE BROWN SHALE
			45	80	BLUE BROWN SHALE
			80	150	CEMENTED GRAVEL; SAND
M:141350	14N 20W 24 ADB 01	INABNIT ELDON	0	11	SOIL DRY CLAY BOULDERS
			11	13	SILT SAND GRAVEL
			13	18	MOIST YELLOW CLAY
			18	65	CEMENTED SILT SAND GRAVEL
			65	120	CEMENTED SAND GRAVEL
M:157207	14N 20W 24 ADDD 01	MISSOULA VALLEY WATER QUALITY DISTRICT	0	2	BLACK LOAM
			2	30	SANDY GRAVEL STRINGERS OF CLAY
			30	35	SAND SOME SMALL GRAVEL WATER
			35	50	GREVELLY SAND SOME TAN CLAY
M:5986	14N 20W 24 adbcb ~~BDBC~~ 01	INABNIT ELDEN & HANSEN PAUL	0	85	SAND & GRAVEL
			85	645	CLAYSTONE & SANDY CLAYSTONE OCCASIONAL COAL SEAMS
			645	1555	SANDY CLAYSTONE ALTERNATING WITH SAND & GRAVEL
			1555	2020	SANDY CLAYSTONE
			2020	2540	SILTSTONE & CLAYSTONE
			2540	2555	CONGLOMERATE
			2555	2605	CLAYSTONE
			2605	2685	SILTY CLAYSTONE

			2685	2700	CONGLOMERATE
			2700	2800	SANDY SILTY CLAYSTONE
			2800	2907	SANDSTONE CLAYSTONE & CONGLOMERATE (BELT SERIES)
M:132328	14N 19W 19 01	EDGELL DAVID	0	2	SOIL
			2	20	GRAVEL
			20	90	DECOMPOSED GRANITE- SAND AND CLAY
			90	120	CLAY
			120	133	DECOMPOSED GRANITE AND COARSE SAND W/WATER
			133	150	DECOMPOSED GRANITE AND CLAY
M:132329	14N 19W 19 01	EDGELL DAVID	0	1	SOIL
			1	22	GRAVEL
			22	60	DECOMPOSED GRANITE AND SAND
			60	100	DECOMPOSED GRANITE W/WATER
M:132887	14N 19W 18 01	MICKELSON TERRY	0	15	YELLOW CLAY AND GRAVEL
			15	19	BROWN CLAY AND GRAVEL
			19	22	BOULDERS CLAY AND GRAVEL
			22	51	BROWN CLAY AND GRAVEL
			51	60	BROWN SHALE
			60	70	BROWN SHALE AND WATER
M:134832	14N 19W 17 B 01	JOHNSON BROTHERS CONTRACTOR	0	4	SOIL
			4	16	BROWN CLAY
			16	23	GRAVEL
			23	26	CLAY
			26	30	GRAVEL (FRACTURED SHALE; ROCK)
			30	100	GREY SHALE; BEDROCK
M:134833	14N 19W 17 B 02	JOHNSON BROTHERS CONTRACTIN	0	1	SOIL
			1	18	CLAY; GRAVEL; SAND
			18	25	GRAVEL
			25	58	SHALE; FRACTURED ROCK (PINK)
			58	100	GRAY BEDROCK
M:134834	14N 19W 18 A 01	JOHNSON BROTHERS CONTRACTOR	0	4	SOIL
			4	27	YELLOW CLAY SHALE
			27	78	BROWN CLAY GRAVEL ROCK CHUNKS
			78	88	GRAVEL CLAY
			88	200	CLAY GRAVEL ROCK CHUNKS
M:136502	14N 19W 18 ADD 01	KESSLER JOE	0	2	SOIL
			2	17	SILT- CLAY & GRAVEL
			17	25	CLAY & GRAVEL
			25	100	BLUE ROCK & BROWN SHALE
M:146121	14N 19W 17 AB 01	BEGITZ KEN	0	6	CLAY

			6	17	WET CLAY
			17	20	CLAY GRAVEL BROKEN ROCK & WATER
			20	60	GRAY SHALE ROCK
			60	80	ROCK & SEEPS OF WATER
			80	100	GRAY SHALE ROCK
M:146122	14N 19W 17 AB 02	BEGITZ KEN	0	40	CLAY GRAVEL & BROKEN ROCK
			40	100	SOFT GRAY SHALE ROCK
M:70809	14N 19W 18 D 01	BENDER ZALE	0	3	BLACK DIRT AND GRAVEL
			3	12	CLAY AND GRAVEL
			12	17	CLAY-GRAVEL AND BOULDERS
			17	40	CLAY- GRAVEL AND SEEPS OF WATER
			40	55	CLAY- GRAVEL AND BOULDERS
			55	57	GRAVEL
			57	88	CLAY- GRAVEL AND BOULDERS
			88	96	BROWN SHALE
			96	102	CLAY AND GRAVEL
			102	105	LIGHT BROWN SHALE
			105	129	CLAY- GRAVEL AND BOULDERS
			129	132	BROWN SHALE
			132	140	CLAY- GRAVEL AND BOULDERS
M:124640	13N 19W 10 C 01	RANDOLPH WILLIAM	0	15	CLAY- GRAVEL AND COBBLESTONES
			15	58	SHALE
			58	59	SHALE AND ROCK
			59	71	HARD ROCK
			71	82	SHALE
			82	85	CLAY AND BOULDERS
			85	140	CLAY- GRAVEL AND BOULDERS
			140	163	SHALE
			163	230	CLAY- GRAVEL AND BOULDERS
			230	300	HARD PINK ROCK
M:127534	13N 19W 09 CDC 01	WASHINGTON CONSTRUCTION CO	0	12	SOIL- GRAVEL
			12	28	GRAVEL- SAND
			28	63	CLAY- GRAVEL
			63	75	GRAVEL- SAND
			75	90	CLAY- GRAVEL
			90	105	GRAVEL- SAND
			105	131	CLAY- GRAVEL
			131	135	GRAVEL- SAND
M:134208	13N 19W 10 DBA 01	MUTH - HILLBERRY DEVELOPMENT	0	10	TOPSOIL- LT. TAN
			10	16	SHALE- COAL- GRAVELY CLAY

			16	20	CLAY TYPE SOIL- DK GRAY
			20	25	CLAY- COAL- SM. GRAVEL DK. BROWN
			25	35	CLAY- COAL- SM. GRAVEL DK. BROWN
			35	45	LT. GRAY- GREEN- CLAY SAND & FINE GRAVEL
			45	50	LT. GRAY- GREEN- CLAY SAND & FINE GRAVEL
			50	55	LT. GRAY- GREEN- CLAY SAND & FINE GRAVEL
			55	60	LT. GRAY- GREEN- CLAY SAND & FINE GRAVEL
			60	65	LT. GRAY- GREEN- CLAY SAND & FINE GRAVEL
			65	68	SEMI LIQUIFIED SANDSTONE GRAVEL- COAL
			68	70	LT. TAN CLAY- BROKEN COAL
			70	75	LT. TAN CLAY- BROKEN COAL
			75	80	LT. TAN CLAY- BROKEN COAL
			80	85	LT. TAN CLAY- BROKEN COAL
			85	91	LT. TAN CLAY- BROKEN COAL
M:134716	13N 19W 10 DAC 01	CLEAVES PAM	0	2	SOIL
			2	19	CLAY ROCK CHUNKS GRAVEL
			19	65	YELLOW BROWN CLAY
			65	75	TAN CLAY GRAVEL
			75	91	BROWN CLAY SHALE
			91	98	BROWN SHALE
M:143121	13N 19W 09 B 01	HAGEN BOB	0	8	SOIL CLAY
			8	27	SAND GRAVEL
			27	90	SAND CLAY SEAMS
			90	94	UNKNOWN
M:143122	13N 19W 10 BA 01	CHRISTOPHER CONSTRUCTION	3	39	SOIL ROCKS
			39	42	GRAVEL SEAM
			42	108	SOFT CLAY
			108	120	CEMENTED GRAVEL CLAY
			120	160	GRAY CLAY
			160	170	PEA-GRAVEL SAND
			170	180	GRAY CLAY
M:145879	13N 19W 10 AA 01	HINES TOM AND LYNNE	0	30	SOIL GRAVEL CLAY
			30	70	CLAY
			70	114	SHALE
			114	121	GRAVEL
			121	195	SHALE
			195	200	COAL
			200	240	SHALE
			240	380	ROCK
M:148266	13N 19W 10 AA 01	SANKEY BRIEN	0	5	TOPSOIL BLACK & ROCKS

			5	10	REDDISH BROWN CLAY
			10	20	GOLD CLAY AND GRAVEL
			20	38	DARK BROWN CLAY
			38	50	LIGHT TAN CLAY AND COAL
			50	130	LIGHT TAN CLAY AND COAL AND GRAVEL & H2O
M:148267	13N 19W 10 DB 01	MUTH FRANKLIN R.	0	7	TOPSOIL BLACK
			7	50	GOLD SAND AND CLAY AND GRAVEL
			50	90	DARK BROWN CLAY AND COAL AND H20
			90	120	GOLD CLAY AND SAND AND GRAVEL AND H20
M:153260	13N 19W 10 ADC 01	ROSSWINKEL KLAUS	0	16	CLAY TAN & GRAVEL
			16	60	TAN CLAY
			60	130	DARK BROWN CLAY & GRAVEL & WATER
M:155821	13N 19W 10 CD 01	CLEAVES KEN	0	2	SOIL
			2	31	CLAY ROCK CHUNKS
			31	55	CLAY SHALE
			55	80	SHALE GRAVEL SEAMS
			80	120	CLAY SHALE GRAVEL
M:68416	13N 19W 09 01	CARLSON JOHN W.	0	92	MOSTLY SANDSTONE
M:68417	13N 19W 09 CB 01	VAN-EVAN CO.	0	2	TOPSOIL
			2	20	TAN CLAY AND GRAVEL
			20	55	YELLOW CLAY AND GRAVEL
			55	74	CLAY AND SAND
			74	108	CLAY SAND AND GRAVEL
			108	117	SAND GRAVEL AND WATER
			117	133	TAN CLAY SAND AND GRAVEL
			133	151	GRAVEL AND CLAY
			151	153	GRAVEL CLAY AND WATER
			153	180	CLAY AND GRAVEL
			180	205	GRAY CLAY AND GRAVEL
			205	213	BROWN CLAY AND GRAVEL
			213	217	BOULDERS AND CLAY
			217	224	BROWN CLAY AND GRAVEL

WELL NO.	YIELD GPM	PERF FROM (FT)	PERF TO (FT)	WATER USE..................
M:120804	25			DOMESTIC
M:122227	8	50	60	DOMESTIC
M:122231	10	60	80	DOMESTIC
M:131022	8.5			DOMESTIC
M:132334	20			DOMESTIC
M:132890	33	138	141	PUBLIC WATER SUPPLY
M:134866	10			DOMESTIC
M:141350	20	95	105	DOMESTIC
M:157207		20	50	MONITORING
M:5986	12.5	645	686	RESEARCH
		889	909	
		970	990	
		1030	1070	
		1150	1191	
		1273	1293	
		1333	1353	
		1497	1537	
		1720	1760	
		1983	2003	
		2125	2145	
		2567	2588	
		2628	2648	
		2689	2709	
		2812	2832	

M:71055	6	80	150	DOMESTIC	
M:71056	0			UNUSED	
M:71057	10			UNKNOWN	
M:71058	4	20	24	UNKNOWN	
M:71059	15	40	80	DOMESTIC	
M:71060	5			DOMESTIC	
M:71061	8			DOMESTIC	
M:71062	15	47	68	DOMESTIC	
M:71063	0			UNUSED	
M:71064	0			UNUSED	
M:71068	4	160	220	DOMESTIC	
M:71069	6	90	100	STOCKWATER	
M:71070	5			DOMESTIC	
M:71071	18			DOMESTIC	
M:71072	50	162	182	DOMESTIC	
				STOCKWATER	
M:71073	30			DOMESTIC	
M:132328	15			DOMESTIC	
M:132329	25			DOMESTIC	
M:132887	20			DOMESTIC	
M:134832	10	18	23	DOMESTIC	
M:134833	25	80	100	DOMESTIC	
M:134834	3	78	88	DOMESTIC	
M:136502	7	18	23	DOMESTIC	
M:146121	15	18	20	DOMESTIC	
M:146122				DOMESTIC	
M:70807				DOMESTIC	
M:70808	3			DOMESTIC	
M:70809	4	17	56	DOMESTIC	
M:70810	90			DOMESTIC	
M:70811	45			DOMESTIC	
M:70812	40			DOMESTIC	
M:70813	3	18	80	DOMESTIC	
M:70814				UNUSED	

M:70815	15			DOMESTIC	
M:70816	50			DOMESTIC	
M:70817	50	0	10	DOMESTIC	
				STOCKWATER	
M:70818	30	41	47	DOMESTIC	
M:70819	50			DOMESTIC	
M:70820	60			DOMESTIC	
M:70821	12	47	53	DOMESTIC	
M:70822	20			DOMESTIC	
M:70823	10			DOMESTIC	
M:70824	17			DOMESTIC	
M:70825				DOMESTIC	
M:124640				UNUSED	
M:127534	0	90	100	DOMESTIC	
M:68417	40	112	118	INDUSTRIAL	
M:134716	12			DOMESTIC	
M:153260	10	90	130	DOMESTIC	
M:134208	20	60	80	DOMESTIC	
M:143122	15	160	170	DOMESTIC	
M:148267	15	60	120	DOMESTIC	
M:68416	50			DOMESTIC	
				STOCKWATER	
M:145879	7	114	121	DOMESTIC	
M:68418				STOCKWATER	
				IRRIGATION	
M:155821	7	65	75	DOMESTIC	
M:148266	10	70	130	DOMESTIC	
M:143121	50			DOMESTIC	

	LOCATION............	SITE NAME...........	TOTAL DEPTH FEET	STATIC WATER LEVEL (FT)	PUMPING WATER LEVEL (FT)	TEST DURATION	WHO DRILLED.............	COMP DATE.......
	14N 20W 27 CCC 01	RYS-SIKORA ADAM/ANNE	106	67	73.5	17	CKC DRILLING	17-Jun-91
M:122227	14N 20W 24 AB 01	INABNIT ELDON	120	42	53	3	JEROME'S DRILLING	15-Jan-91
M:122231	14N 20W 24 AD 01	INABNIT ELDON	140	38	58	4	JEROME'S DRILLING	16-Jan-91
M:131022	14N 20W 24 ADD 01	TAG RICHARD & PHYLLIS	70	2	45	2.5	CKC	5-Oct-92
M:132334	14N 20W 24 01	SORENSEN BOB	130	85	99	1	JEROME'S	6-Nov-92
M:132890	14N 20W 26 CCCB 01	MOUNTAIN WATER COMPANY * WELL 28	375	78	116	20	CAMP WELL	21-Sep-72
M:134866	14N 20W 24 ADB 01	INABNIT STEVEN	150	120		1	JEROME'S	4-Jun-93
M:141350	14N 20W 24 ADB 01	INABNIT ELDON	120	20		1	JEROME'S	7-Mar-94
M:157207	14N 20W 24 ADDD 01	MISSOULA VALLEY WATER QUALITY DISTRICT	50	27			MISSOULA WQ DISTRI	16-Jan-96
M:5986	14N 20W 24 BDBC 01	INABNIT ELDEN & HANSEN PAUL	2907	2.7	120	43.5	LIBERTY	28-Aug-78

M:71055	14N 20W 23 DAB	FIRST NAT'L BANK	160	80	104			1-Jan-75
M:71056	14N 20W 23 DAB	FIRST NAT'L BANK	100					1-Jan-76
M:71057	14N 20W 23 DAB	POMEROY MIKE	80	34	46			1-Jan-82
M:71058	14N 20W 23 DAB	PALAKOW ALEX	78	20	22			1-Jan-82
M:71059	14N 20W 24 A	BRAMMER GERALD	80	43	75			1-Jan-76
M:71060	14N 20W 24 A	BRAMMER GERALD	200	70	180			1-Jan-76
M:71061	14N 20W 24 A	TAG RICHARD	85	0	75			1-Jan-71
M:71062	14N 20W 24 A	MCCLURE HOWARD	68	18	40			1-Jan-70
M:71063	14N 20W 24 ACA	INABNIT ELDON	200					1-Jan-87
M:71064	14N 20W 24 ACA	INABNIT ELDON	160					1-Jan-87
M:71068	14N 20W 26 DC	BALL LEWIS	240	77	230			1-Jan-74
M:71069	14N 20W 27 AB	HANSON PAUL	120	70	80			1-Jan-77
M:71070	14N 20W 27 C	O AND T ENTERPRISES	130	65	65			1-Jan-76
M:71071	14N 20W 27 C	KVALSTEN BILL	100	50	60			1-Jan-78
M:71072	14N 20W 27 CBA	AMMONS ROB & CAROL	182	73	126			1-Jan-72
M:71073	14N 20W 27 CBC	AMMONS ROB & CAROL	223	70	161			1-Jan-74
M:132328	14N 19W 19 01	EDGELL DAVID	150	77	96	2	JEROME'S	9-Apr-84
M:132329	14N 19W 19 01	EDGELL DAVID	100	25	44	1	JEROME'S	18-Apr-84
M:132887	14N 19W 18 01	MICKELSON TERRY	70	40	50	1	CAMP WELL	10-Aug-71
M:134832	14N 19W 17 B 01	JOHNSON BROTHERS CONTRACTORS	100	10	32	1	JEROME'S DRILLING	29-Mar-93
M:134833	14N 19W 17 B 02	JOHNSON BROTHERS CONTRACTING	100	5	15	1	JEROME'S	1-Apr-93
M:134834	14N 19W 18 A 01	JOHNSON BROTHERS CONTRACTORS	200	50	67	1	JEROME'S	31-Mar-93
M:136502	14N 19W 18 ADD 01	KESSLER JOE	100	10		1	JEROME'S	21-Jun-93
M:146121	14N 19W 17 AB 01	BEGITZ KEN	100	6	20	1	CAMP	5-Dec-94
M:146122	14N 19W 17 AB 02	BEGITZ KEN	100				CAMP	6-Dec-94
M:70807	14N 19W 17	DODD WALTER	152	45	45			1-Jan-72
M:70808	14N 19W 17 CB	DODD BYRON	200	20				1-Jan-73
M:70809	14N 19W 18 D 01	BENDER ZALE	140	9	60	2	CAMP WELL DRILLING	8-Dec-76
M:70810	14N 19W 18 D	KAISER JOSEPH	85	27	37			1-Jan-73
M:70811	14N 19W 18 D	MCKAY JOHN R	60	35	45			1-Jan-77
M:70812	14N 19W 18 D	THOMPSON ROGER	36	7	32			1-Jan-76
M:70813	14N 19W 18 D	HIMES THOMAS	80	3	60			1-Jan-76
M:70814	14N 19W 18 D	JOHNSHOY GLEN	300					1-Jan-79

70815	14N 19W 18 D	BRICKER ROBERT	58	25	35			1-Jan-72
70816	14N 19W 18 D	HOLMLOND JULIA F.						1-Jan-69
70817	14N 19W 18 DB	NELSON JOHN & AMY	10	2	3			1-Jan-63
70818	14N 19W 19	WOOD PATRICK J.	60	5	40			1-Jan-84
0819	14N 19W 19 BA	NEST JOHN	37	6	16			1-Jan-72
0820	14N 19W 19 BC	DELAND LOREN	74	0	20			1-Jan-72
0821	14N 19W 19 BCC	FORD JIM	180	34	60			1-Jan-79
0822	14N 19W 19 BD	EDGELL DAVID	100	38	53			1-Jan-76
M:70823	14N 19W 19 CD	TURK JAE	30	10	20			1-Jan-73
M:70824	14N 19W 19 D	LEDNARD KATHERINE	59	12	55			1-Jan-78
M:70825	14N 19W 19 DAC	BARGFELD CHESTER	58		58			1-Jan-54
M:124640	13N 19W 10 C 01	RANDOLPH WILLIAM	300				CAMP WELL	24-Oct-91
M:127534	13N 19W 09 CDC 01	WASHINGTON	135	50	72	1	JEROME'S	17 APR 1992
		CONSTRUCTION CO						
M:68417	13N 19W 09 CB 01	VAN-EVAN CO.	224	55	110	4	CAMP WELL	27 FEB 1969
M:134716	13N 19W 10 DAC 01	CLEAVES PAM	98	30		1	JEROME'S	9-Jun-93
M:153260	13N 19W 10 ADC 01	ROSSWINKEL KLAUS	130	60	100	2	LEWIS	10-Nov-95
M:134208	13N 19W 10 DBA 01	MUTH - HILLBERRY	91	-2	73	4	PHIL LEWIS	10-Feb-93
		DEVELOPMENT						
M:143122	13N 19W 10 BA 01	CHRISTOPHER	180	86		1	JEROME'S	11-May-94
		CONSTRUCTION						
M:148267	13N 19W 10 DB 01	MUTH FRANKLIN R.	120	28	50	2	LEWIS WATER WELL	28-Oct-94
M:68416	13N 19W 09 01	CARLSON JOHN W.	92	62				1-Apr-45
M:145879	13N 19W 10 AA 01	HINES TOM AND LYNNE	380	80		3	JEROMES	11-Nov-94
M:68418	13N 19W 10 C 01	RANDOLPH WILLIAM H.	180					1-Jun-15
M:155821	13N 19W 10 CD 01	CLEAVES KEN	120	18		2	JEROME'S	3-Jun-96
M:148266	13N 19W 10 AA 01	SANKEY BRIEN	130	32	90	3	LEWIS WATER WELL	20-Oct-94
M:143121	13N 19W 09 B 01	HAGEN BOB	94	1		1	JEROME'S	5-May-94

APPENDIX 3

MB-4

Location: NW1/4SE1/4NE1/4 sec. 24, T. 14 N., R. 20 W.
Total depth: 2,907 feet (886.05 m)
Spud date: July 20, 1978
Completion date: August 28, 1978
Rig: Gardner Denver Model 2000, X-L Drilling Rig No. 7
Drill pipe: 2-7/8 inch (7.30 cm) x 1-1/2 inch (3.81 cm) x 20 feet (6.10 m)
Drill collars: Seven 4-1/2 inch (11.43 cm) x 1-1/2 inch (3.81 cm) x 20 feet (6.10 m)
Sample interval: 10 feet (3.05 m)
Coring interval: 695 feet to 710 feet (211.84 m to 216.41 m), 710 feet to 718 feet (216.41 m to 218.85 m), 826 feet to 841 feet (251.76 m to 256.34 m), 1,489 feet to 1,504 feet (453.85 m to 458.42 m), 2,395 feet to 2,410 feet (730.00 m to 734.57 m), 2,895 feet to 2,907 feet (882.40 m to 886.05 m).
Total core recovered: 46.3 feet (14.11 m)
Core barrel: 4-5/8 inch (11.75 cm) x 3 inch (7.62 cm) x 15 feet (4.57 m)

Borehole history: Hole MB-4 was spudded with a 12-1/4 inch (31.12 cm) bit and drilled to a depth of 115 feet (35.05 m). 6-5/8 inch (16.83 cm) casing was installed, butt welded in approximately 30 foot (9.14 m) lengths and cemented to 115 feet (35.05 m). Blow out prevention equipment was mounted to the casing head. A 6 inch (15.24 cm) diameter hole was drilled to 2,895 feet (882.40 m) with spot cores run at the noted intermediate depths and a bottom hole core run from 2,895 feet (882.40 m) to terminal depth. Penetration rates were generally slow and bit wear was high due to the abrasive nature of the quartzite conglomerate encountered. Cones sheared off the bit at 1,300 feet (396.24 m) but were milled out to complete the hole successfully. The circulation systems used consisted of earthen pits having approximately 15,000 gallons (56,775 l) total capacity. Drilling fluid was primarily a gel base with organic polymers and other additives. Viscosity averaged 39.9 sec/qt and the weight averaged 9.35 pounds per gallon on August 12, 1978.

The hole was logged by Goodwell, Inc. prior to the break period and again at the completion of the hole on August 27, 1978. Responsibility for the hole was transferred to the Montana Bureau of Mines who installed 4 inch (10.16 cm) casing to a depth of 2,863.1 feet (872.67 m) for hydrologic testing and observation purposes.

Bit Record MB-4

			Size		In		Out		Footage	
No.	**Make**	**Type**	**in.**	**cm**	**ft**	**m**	**ft**	**m**	**ft**	**m**
1	HTC	OSC	12-1/4	31.12	0	0	115	35.05	115	35.05
2	GW	GR-4	6	15.24	115	35.05	475	144.78	360	109.73
3	GW	GR-4	6	15.24	475	144.78	695	211.84	220	67.06
4	Varel	H-2	6	15.24	695	24.84	826	251.76	131	39.93
5	GW	GR-4	6	15.24	826	251.76	975	297.18	149	45.42
5A	GW	GR-4	6	15.24	975	297.18	1,030	313.94	55	16.76
6	Varel	H-2	6	15.24	1,030	313.94	1,095	333.76	65	19.81
7	GW	GR-1H	6	15.24	1,095	333.76	1,195	364.24	100	30.48
8	GW	GR-4	6	15.24	1,195	364.24	1,295	394.72	100	30.48
9	GW	GR-1H	6	15.24	1,295	394.72	1,355	413.00	60	18.29
10	GW	GR-1H	6	15.24	1,355	413.00	1,489	453.85	134	40.84
11	GW	GR-1H	6	15.24	1,489	453.85	1,695	516.64	206	62.79
12	GW	GR-4	6	15.24	1,695	516.64	1,885	574.55	190	57.91
13	GW	GR-4	6	15.24	1,885	574.55	2,155	656.84	279	82.30
14	GW	GR-4	6	15.24	2,155	656.84	2,395	730.00	240	73.15
15	GW	GR-4	6	15.24	2,395	730.00	2,603	793.39	208	63.39
16	GW	GR-4	6	15.24	2,603	793.39	2,755	839.72	152	46.33
17	GW	GR-4	6	15.24	2,755	839.72	2,895	882.40	140	42.67

Note: GW--Gruner Williams

Mud Record MB-4

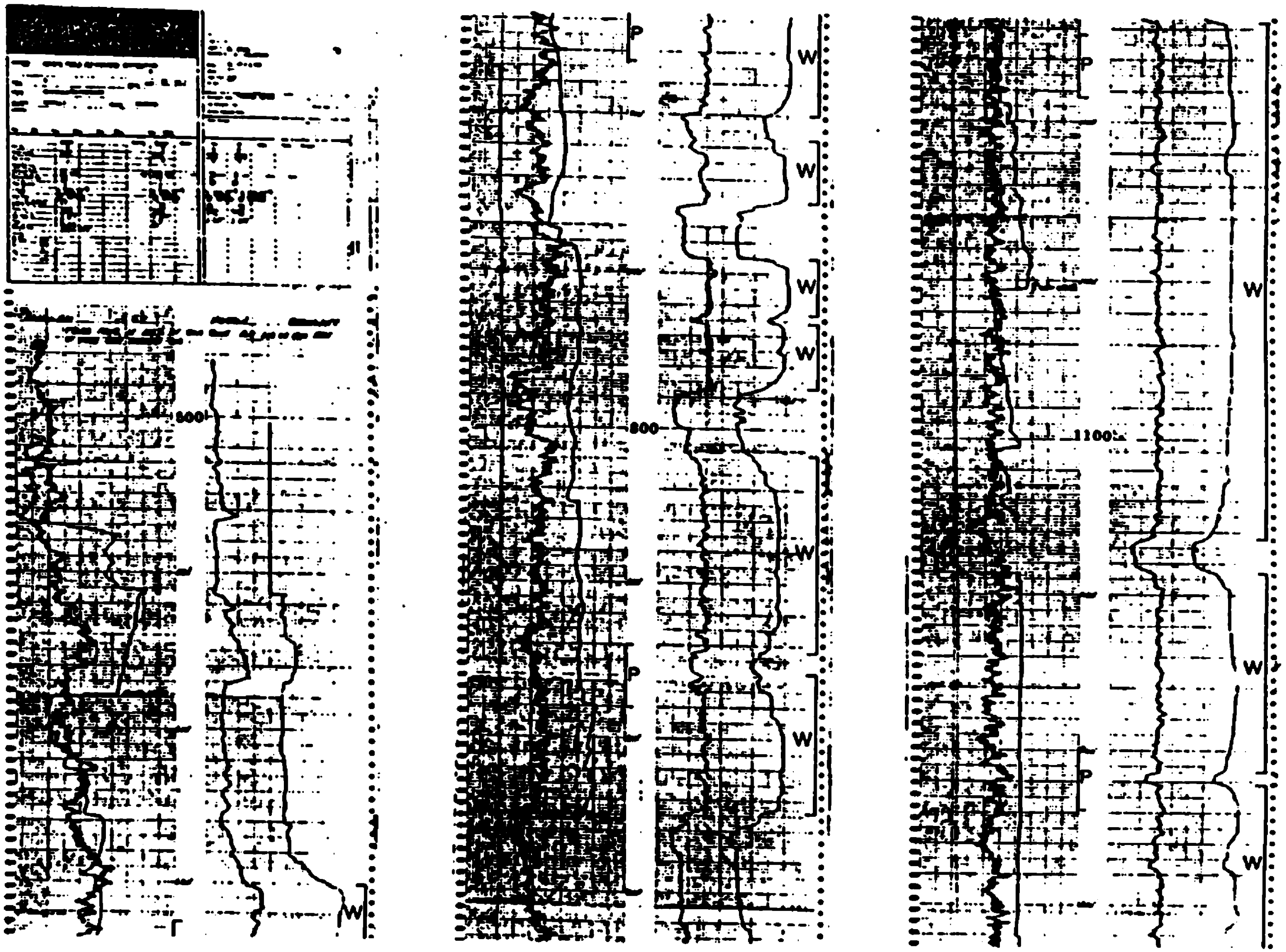
Material	**Quantity**
Gel	109 sks (100 lbs/45.36 kg ea)
Lime	1 sk (50 lbs/22.68 kg ea)
Driscose	1 sk (50 lbs/22.68 kg ea)
Cedar Fiber	2 sks (50 lbs/22.68 kg ea)
Rayvan	4 sks (50 lbs/22.68 kg ea)
Surfdrill	13 cans (5 gal/22.73 l ea)
Cypan	26 sks (50 lbs/22.68 kg ea)

Deviation Tests MB-4

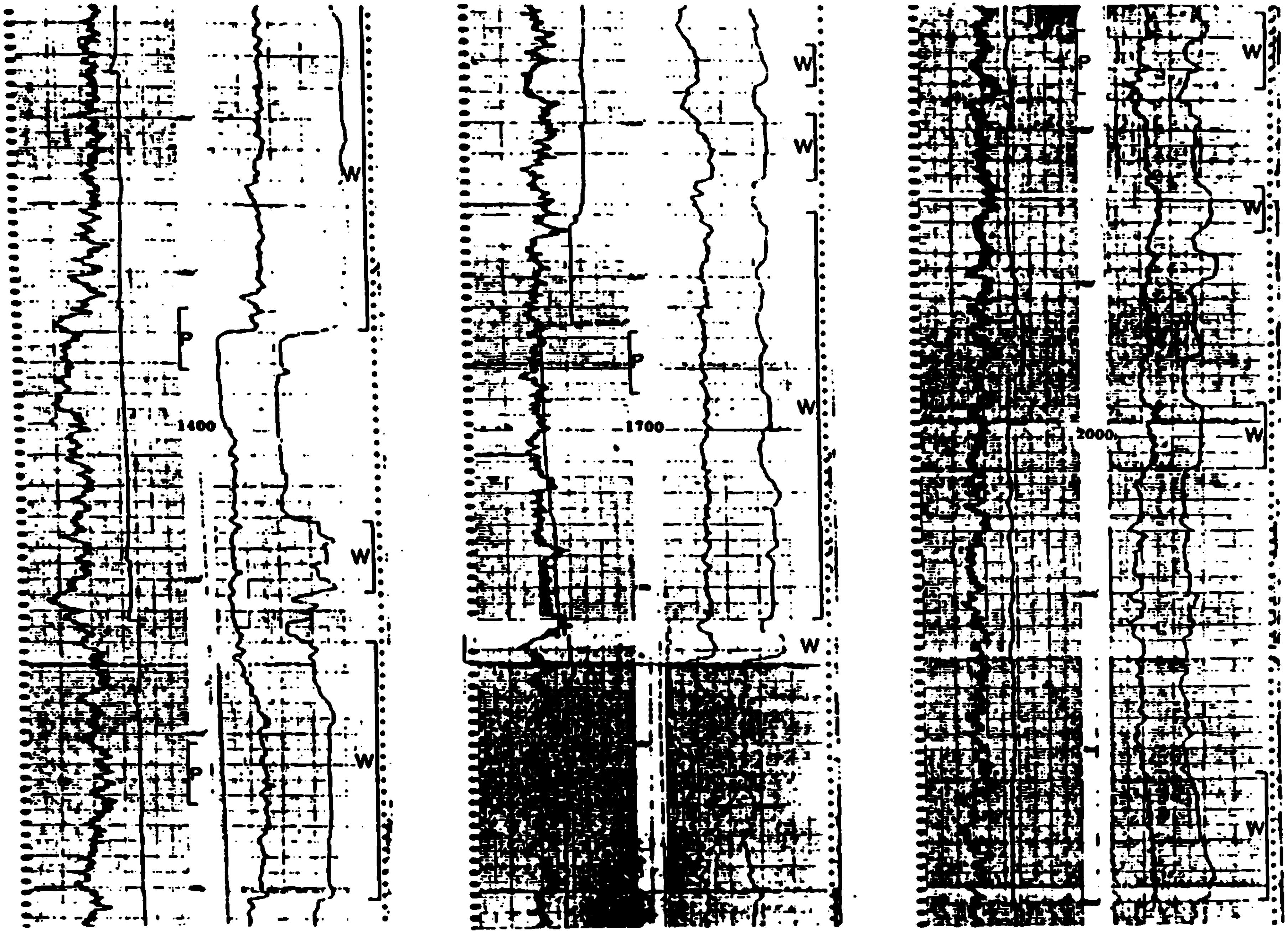
Depth	Deviation
115 feet (35.05 m)	1/2°
690 feet (210.31 m)	4°
846 feet (257.86 m)	5°
975 feet (297.18 m)	5°
1,095 feet (333.76 m)	4°
1,353 feet (412.39 m)	8°
1,920 feet (585.22 m)	4°

Geophysical Logs MB-4

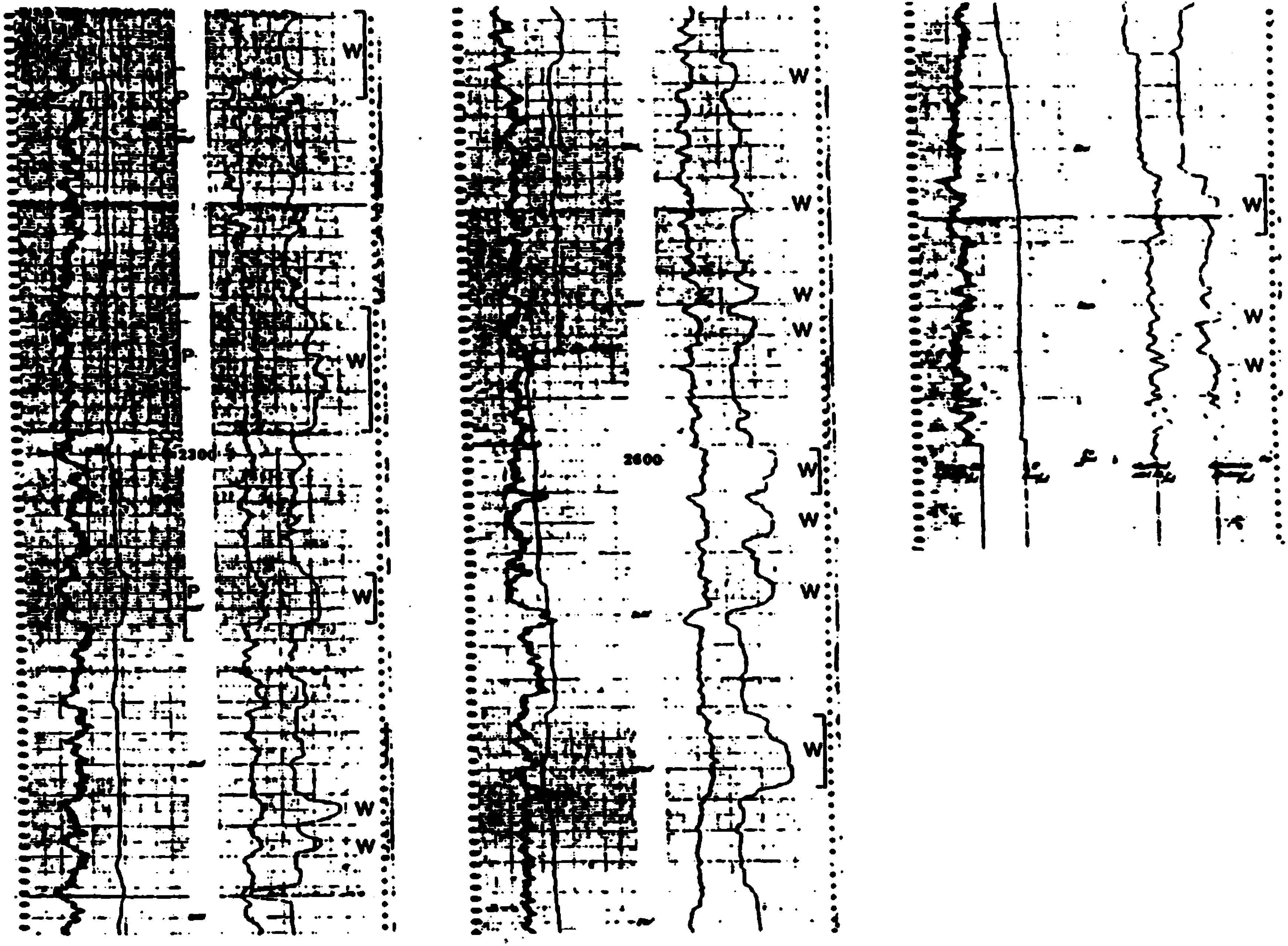
Gamma
Density
Spontaneous Potential
Resistivity
Caliper
Neutron



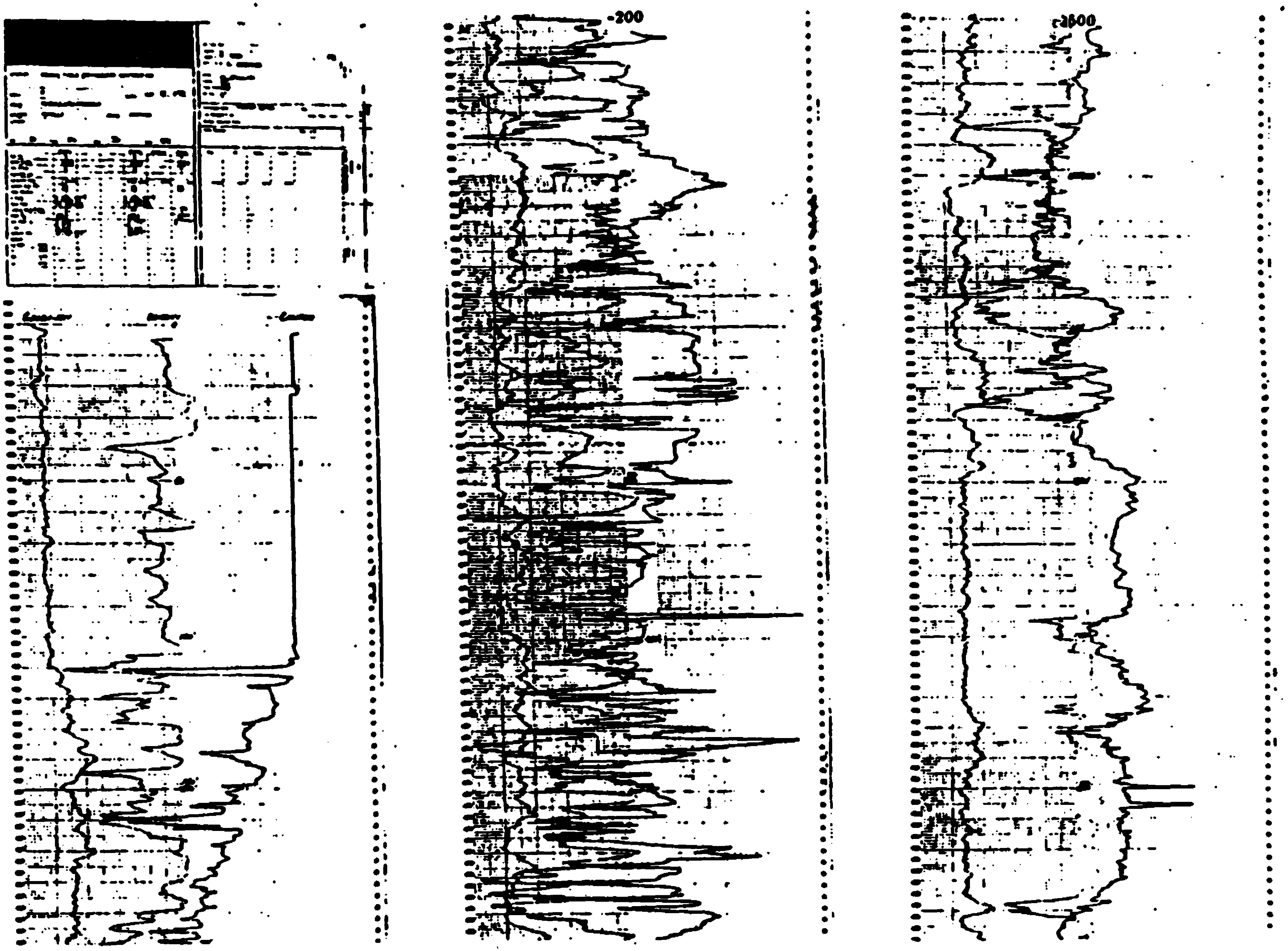
Hole 4. Gamma, Spontaneous Potential, Neutron, and Resistivity logs.



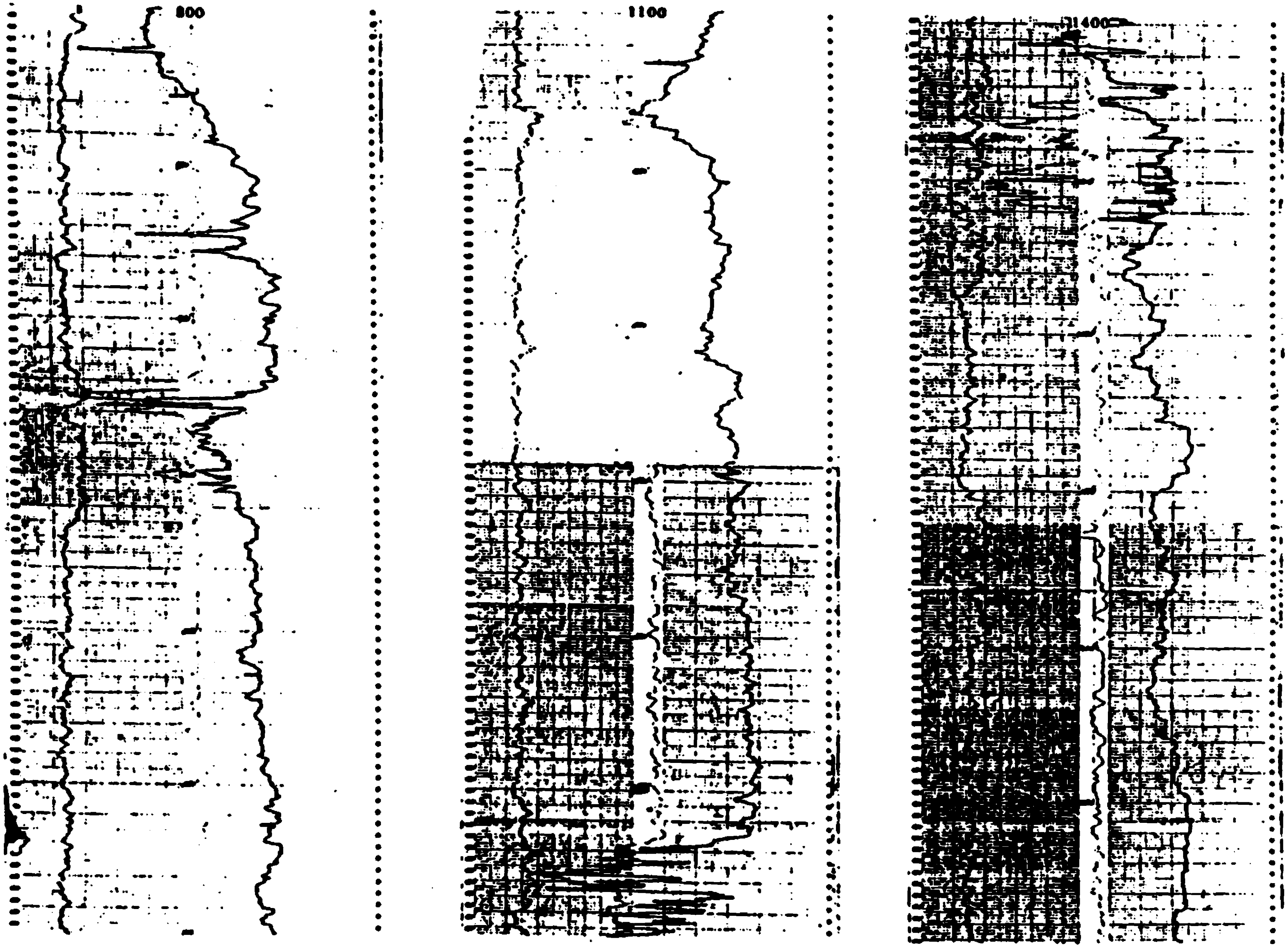
Hole 4. Gamma, Spontaneous Potential, Neutron, and Resistivity logs.



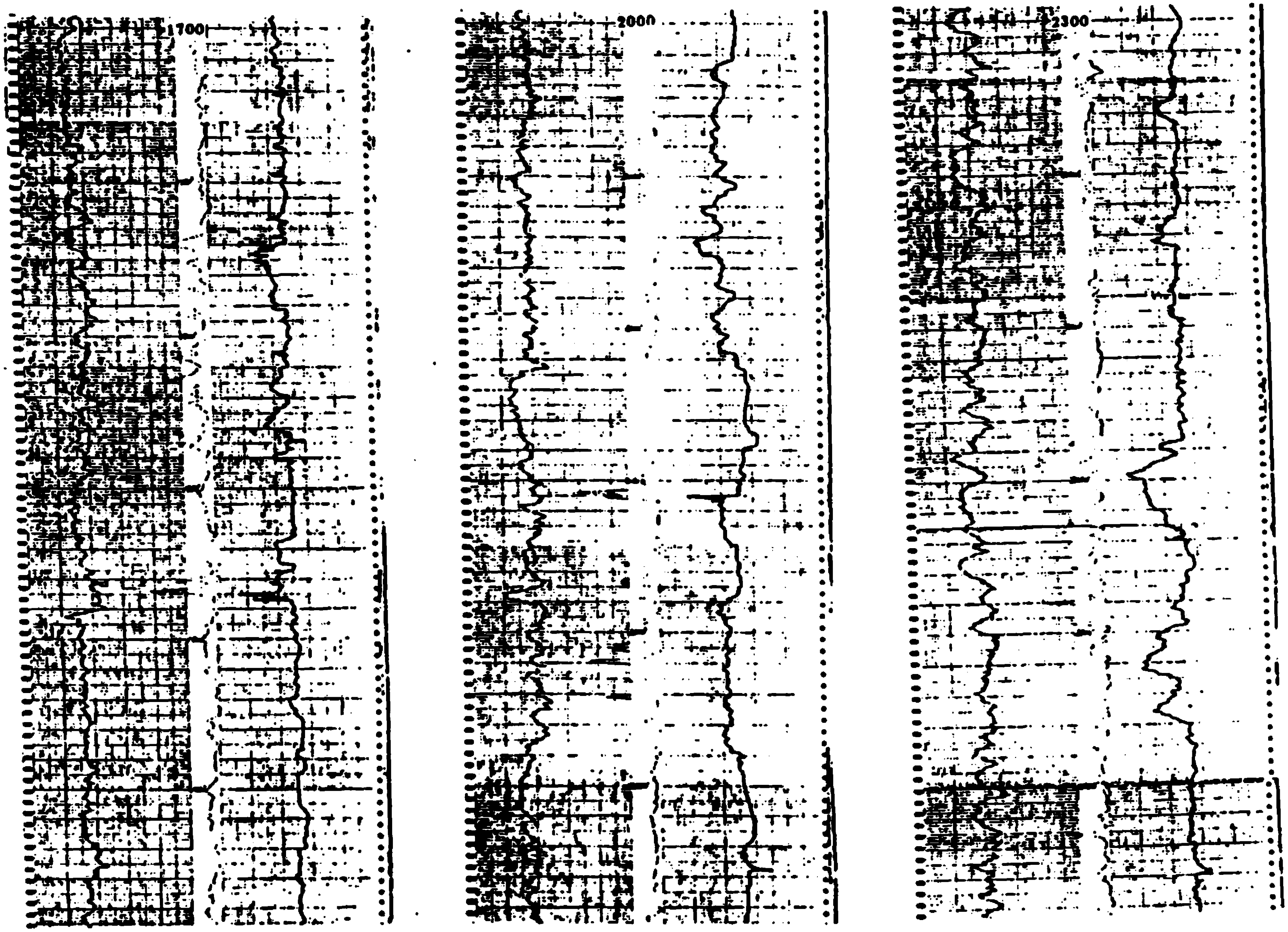
Hole 4. Gamma, Spontaneous Potential, Neutron, and Resistivity logs.



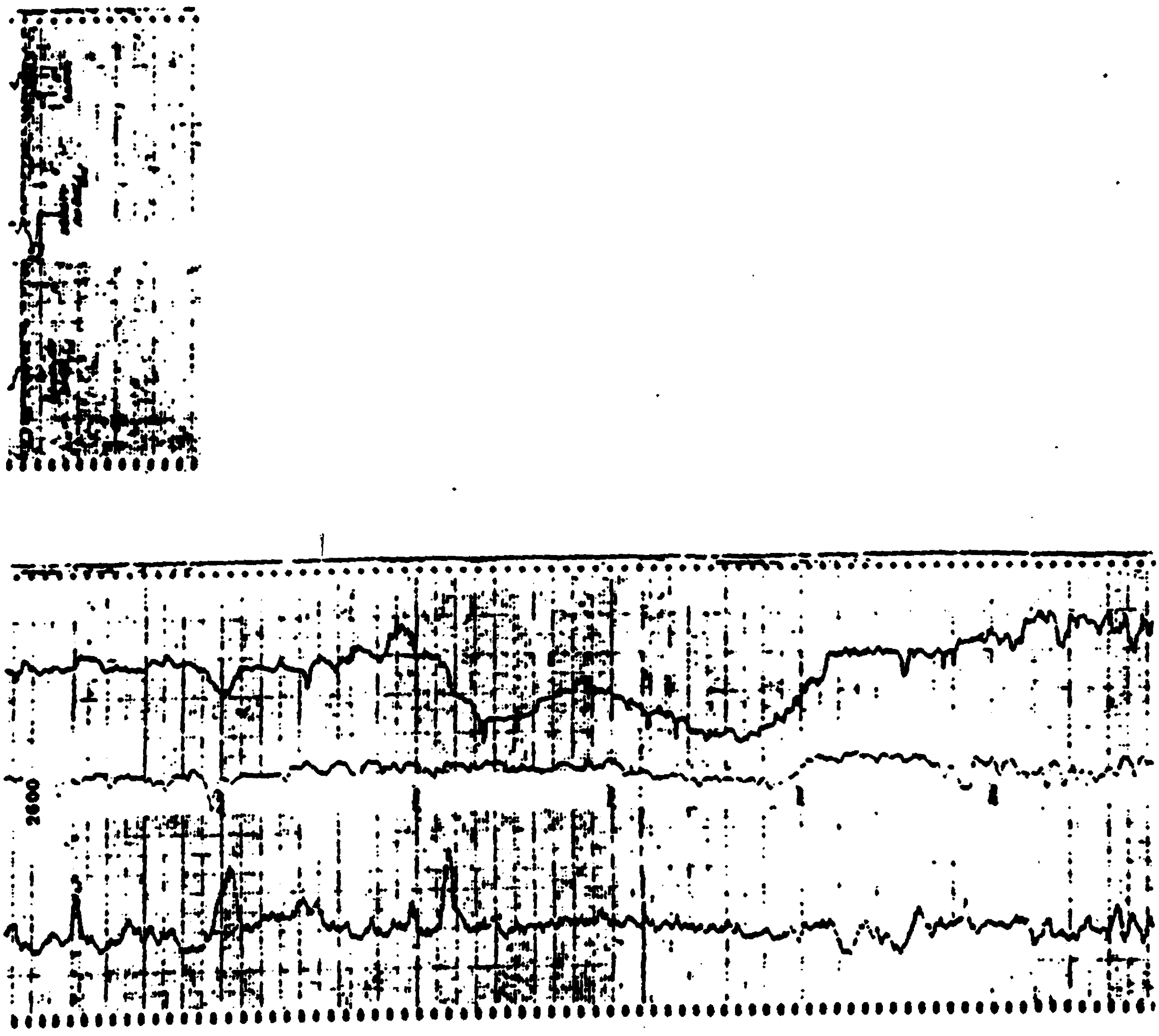
Hole 4. Gamma, Density, and Caliper logs.



Hole 4. Gamma, Density and Caliper Logs



Hole 4. Gamma, Density, and Caliper logs.



Hole 4 Gamma, Density, and Caliper logs.

Hole #4 Casing T. D. 2907

Depth at top of joint	Length	Depth at top of joint	Length
2863.1-bottom of casing		[1497.1	20.0
2852.6	10.5	1456.4	40.7
2832.0	20.6	1415.2	41.2
[2812.0	20.0	1373.9	41.3
2771.9	40.1	1353.3	20.6
2730.6	41.3	[1333.3	20.0
2709.9	20.7	1293.3	40.0
[2689.3	20.6	[1273.3	20.0
2648.0	41.3	1231.6	41.7
[2628.0	20.0	1190.9	40.7
2588.0	40.0	[1170.9	20.0
[2567.4	20.6	[1150.3	20.6
2526.8	40.6	1110.3	40.0
2486.7	40.1	1070.3	40.0
2446.7	40.0	[1050.3	20.0
2405.4	41.3	[1030.3	20.0
2365.4	40.0	989.6	40.7
2325.4	40.0	[969.6	20.0
2285.4	40.0	929.6	40.0
2245.3	40.1	909.0	20.6
2205.3	40.0	[889.0	20.0
2165.3	40.0	849.0	40.0
2144.7	20.6	828.4	20.6
[2124.7	20.0	788.4	40.0
2084.7	40.0	747.1	41.3
2044.7	40.0	706.5	40.6
2003.4	41.3	685.9	20.6
[1983.4	20.0	[665.9	20.0
1943.4	40.0	[645.9	20.0
1903.4	40.0	605.3	40.6
1863.4	40.0	584.6	20.7
1822.1	41.3	564.0	20.6
1780.8	41.3	543.4	20.6
1760.2	20.6	522.8	20.6
[1740.2	20.0	502.2	20.6
[1720.2	20.0	481.5	20.7
1679.6	40.6	461.5	20.0
1639.6	40.0	441.5	20.0
1619.0	20.6	421.5	20.0
[1599.0	20.0	401.5	20.0
1557.7	41.3	381.5	20.0
1537.1	20.6	361.5	20.0
[1517.1	20.0	341.5	20.0

[Indicates perforated interval

Hole #4 cont. Casing T. D. 2907

Depth at top of joint	Length
321.5	20.0
301.5	20.0
281.5	20.0
261.5	20.0
240.9	20.6
220.3	20.6
199.6	20.7
179.6	20.0
159.6	20.0
138.9	20.7
118.3	20.6
97.7	20.6
77.7	20.0
57.7	20.0
37.1	20.6
16.5	20.6
+1.6	18.1

6 inch surface casing from 0 to 115 feet

MONTANA BUREAU OF MINES AND GEOLOGY AQUIFER TEST DATA No. 4 9-17-79 GROUND-WATER DIVISION

State Montana County Missoula T. 14 [✓ N] S. R. 20 E. [✓ W] Sec. 24 . Tract adbcb

Personnel Norbeck Gemmell
Paul Hansen

Test type: [✓ 1. Single well drawdown] [✓ 2. Single well recovery] 3. Drawdown with obs. well 4. Recovery with obs. well 5. Other (specify)

Well owner Elden Inabnit Address

Driller XL Drilling

Method drilled: A. Air-rotary B. Bored or augered C. Cable-tool D. Dug [✓ H. Hyd.-rotary] J. Jetted P. Air percussion R. Rev.-rotary T. Trenching V. Driven W. Drive-wash Z. Other

Total well depth 290 ft. Well diameter 6 in.

Casing diameter 4 in. Casing type Fe

Type of screen or perforation torch slots Interval of screen or perforation Pump hp. & type ¾ hp sub Pump depth 290 ft.

Aquifer Tertiary seds Precambrain Belt Aquifer lithology

Altitude of land surface 3538 How determined Survey MP Above/Below LSD 2.33 Altitude MP

SWL from MP 23.84, 9-17, 2:08P How measured M-Scope

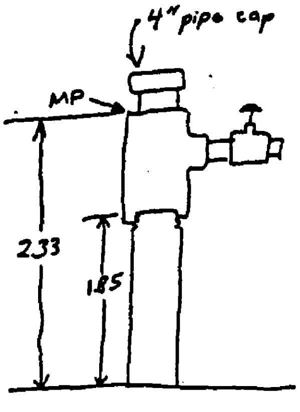
Date and hour	Time t (minutes)	t' (min)	t/t'	Drawdown s (ft)	Q (gpm)	Orifice bucket (FT)			
9-17,2:10P	0			0					
	1.50			8.45	8.82				
	2.65			22.58					
	3.00			28.78					
	4.18			36.79	7.50				
	6.08			45.40	7.50				
	8.08			52.46					
	10.00			57.57	7.32				
	12.08			61.80					
	14.00			65.04	7.32				
	16.07			67.93					
	20.00			72.74					
	25.00			76.24	7.14				
	30.00			80.33					
	40.00			84.71	7.32				
	50.10			86.24					
	60.02			87.67					
	79.98			90.88					
	100.00			91.28					
	120.10			92.51					
	151.50			94.41					
	181.00			95.67					
	210.00			96.62					
9-17,6:10P	240.00	0		97.59					
	241.00	1.00	241.00	85.84					
	242.10	2.10	115.29	75.81					
	242.97	2.97	81.81	68.74					
	243.94	3.94	61.91	61.80					
	244.97	4.97	49.29	55.80					
	247.01	7.01	35.24	45.29					
	250.10	10.10	24.76	34.70					C 33

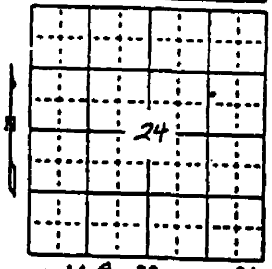
Date and hour	Time t (minutes)	t' (min)	t/t'	Drawdown s (ft)					
	253.75	13.75	18.45	27.07					
	256.06	16.06	15.94	24.32					
	260.07	20.07	12.96	21.39					
	268.47	28.47	9.43	16.17					
	285.91	45.91	6.23	13.94					
	315.29	75.19	4.19	9.95					
	341.61	101.61	3.36	8.80					
	384.65	144.65	2.66	6.73					
	416.26	176.26	2.36	5.94					
	481.73	241.73	1.99	4.73					
	1090.0	850.0	1.28	1.93					
	1168.0	928.0	1.26	1.80					
	1475.0	1235.0	1.19	6.19					
	1530.0	1290.0	1.19	3.11					
	1646.0	1406.0	1.17	2.64					
	2720.0	2480.0	1.10	1.41					

WELL LOG

Depth Feet		Material
From	To	

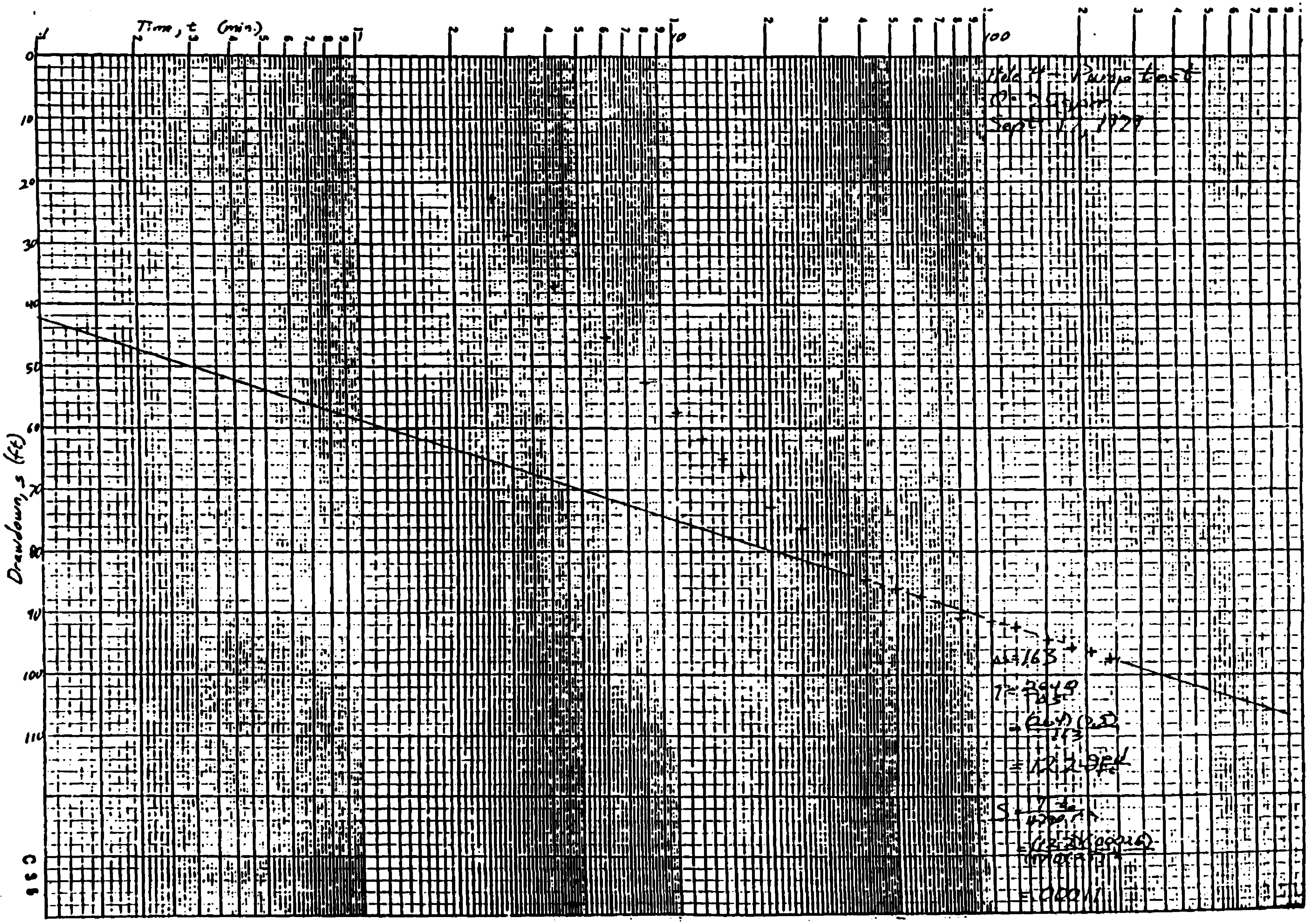
REMARKS & SKETCH

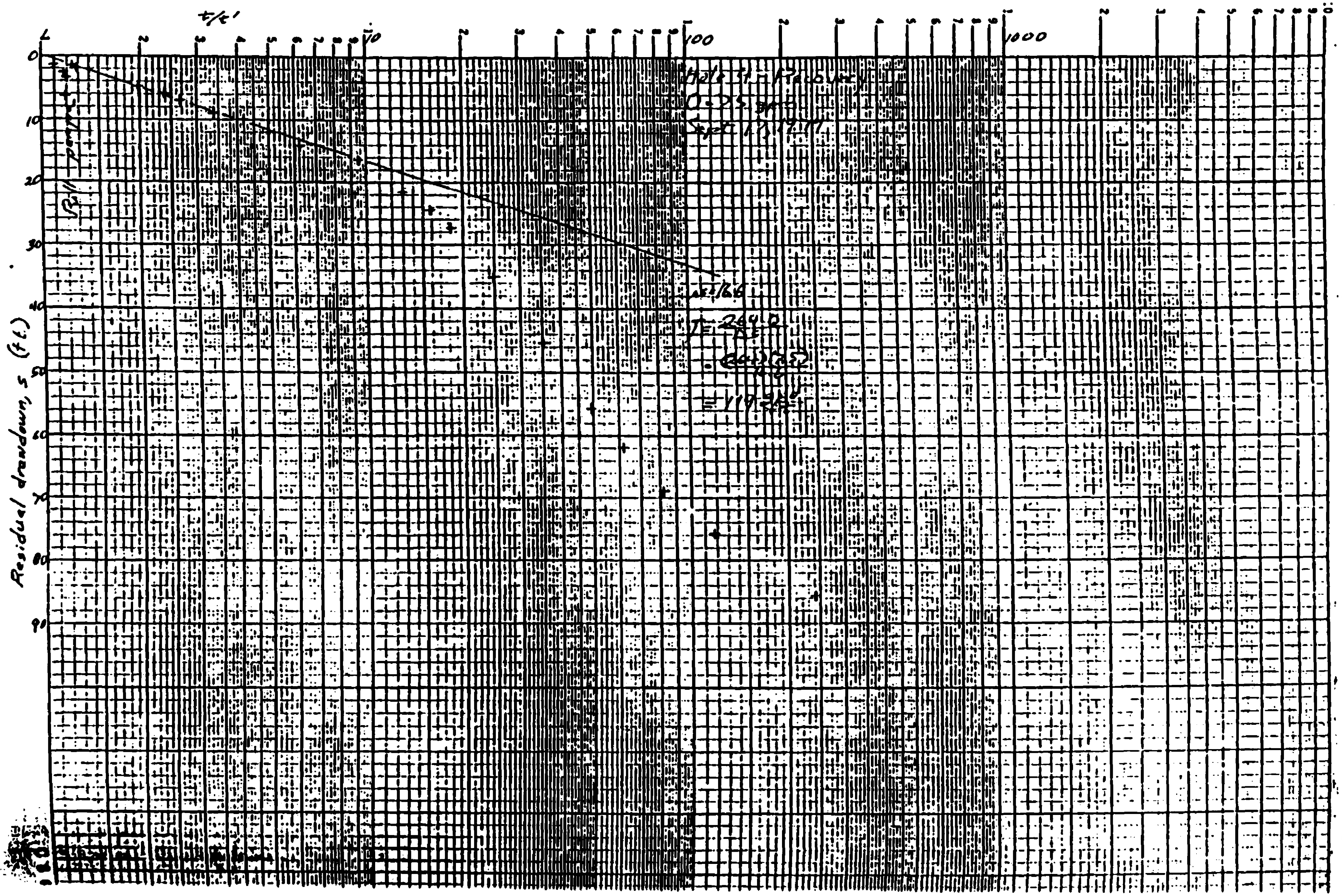




T. 14 N R. 20 E Sec. 24
TRACT adbcb

T
T = ____________ gpd/ft SC = ____________ gpm/ft
S = ____________ OW SAMPLE NO. ____________


Time, t (min.)
1
10
100
Drawdown, s (ft)
0
10
20
30
40
50
60
70
80
90
100
110
Well H - Pump test
Q = [illegible]
Sept [illegible], 1929
Δs = 16.3
T = 264 Q / Δs
= (264)(2.5) / 16.3
= 12.2 [illegible]
S = T t₀ / 4790 r²
= (12.2)(.00026) / [illegible]
= .00011
C 3 8


t/t'
1
10
100
1000
0
10
20
30
40
50
60
70
80
90
Residual drawdown, s (ft.)
Hole 11 - Recovery
Q = 25 gpm
Sept 17, 1981
Δs = 26
T = 264 Q/Δs
= (264)(25)/26
= 119 [illegible]

issoula, Bitterroot Drilling Project Summer 1978

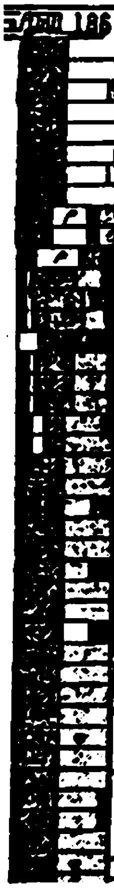
STATE ntana	Bendix Field Engineering Corp. COMPANY
UNTY ssoula	FARM — WELL NO. No. 4
CE ¼ SE¼ NE¼	SURVEY Elevation ≈ 3530'
sec. 24	
T. 4N — R. R20W	TOTAL DEPTH 2907'
	COMMENCED July 20, 1978
	COMPLETED
	REMARKS
ALTITUDE 3530'	
PRODUCTION	Logged by: David Quattlebaum

end:
conglom, gravel
Sandstone, sand
siltstone, silt
claystone, clay
coal
pyrite (tr)
organic mat.
illite

CASING RECORD

SHOT	QUARTS	BETWEEN

186 TULSA, OKLAHOMA 74101 PRINTED IN U.S.A.



gran.-f, ang-rnd (ang)+(rnd) frags of Qtzt, [illegible] Qz, [illegible] pale yell; Fld, [illegible] [illegible]

[illegible]

[illegible]

[illegible]

[illegible] Qtz; [illegible] Qz; com Cly; tr-mnr Coal

s pbl-crs, ang-(rnd) frags of SHst, cly, (mic), [illegible]; Clst, (sHy), (calc), lt gy, lt-med brn; Cly, lt gy, lt gn, lt-med brn; tr-mnr Qtzt, [illegible], lt gy, pk, [illegible], dk gn; tr-com dk brn-blk Coal + Lignite;
Note: Qtzt absent in some samples.
Qz + Fld entirely absent. This interval pred Clst, slty & SHst, cly.

s pbl-med, ang-(ang) frags of Sltst, cly, (calc), (mic), lt gy-(gy brn, gy) [illegible]; Clst, (sHy), (calc), lt gy-lt brn; mnr Cly, lt-med brn, to gn; tr-mnr dk brn-blk Coal + Lignite; small tr Qtzt, lt gy; tr (brd) bronze, shiny metallic xls.
Note: Clst often contains inclusions of blk org mat.

s pbl-med, ang-(rnd) frags of SHst, cly, (mic), (calc), com, lt-m brn, lt-m gy, (gy) [illegible], to dk brn; Clst, (sHy), (calc), lt-m brn, lt-m gy; mnr Cly, m brn, lt gy; tr-mnr Coal + Lignite; tr Qz, [illegible]; tr Qtzt, red, wh, lt gy; tr [illegible] frags [illegible] on some grs; 470-480': as above with abnt Cly, wh; 470-490': as above with abnt dk brn-blk Lig + Coal.

[illegible]

[illegible]

[illegible]

[illegible]

700-718' CORE

718-750': NO SAMPLES

[illegible]

[illegible]

same as 890'-900' below.

[illegible]

[illegible]

[illegible]

[illegible]

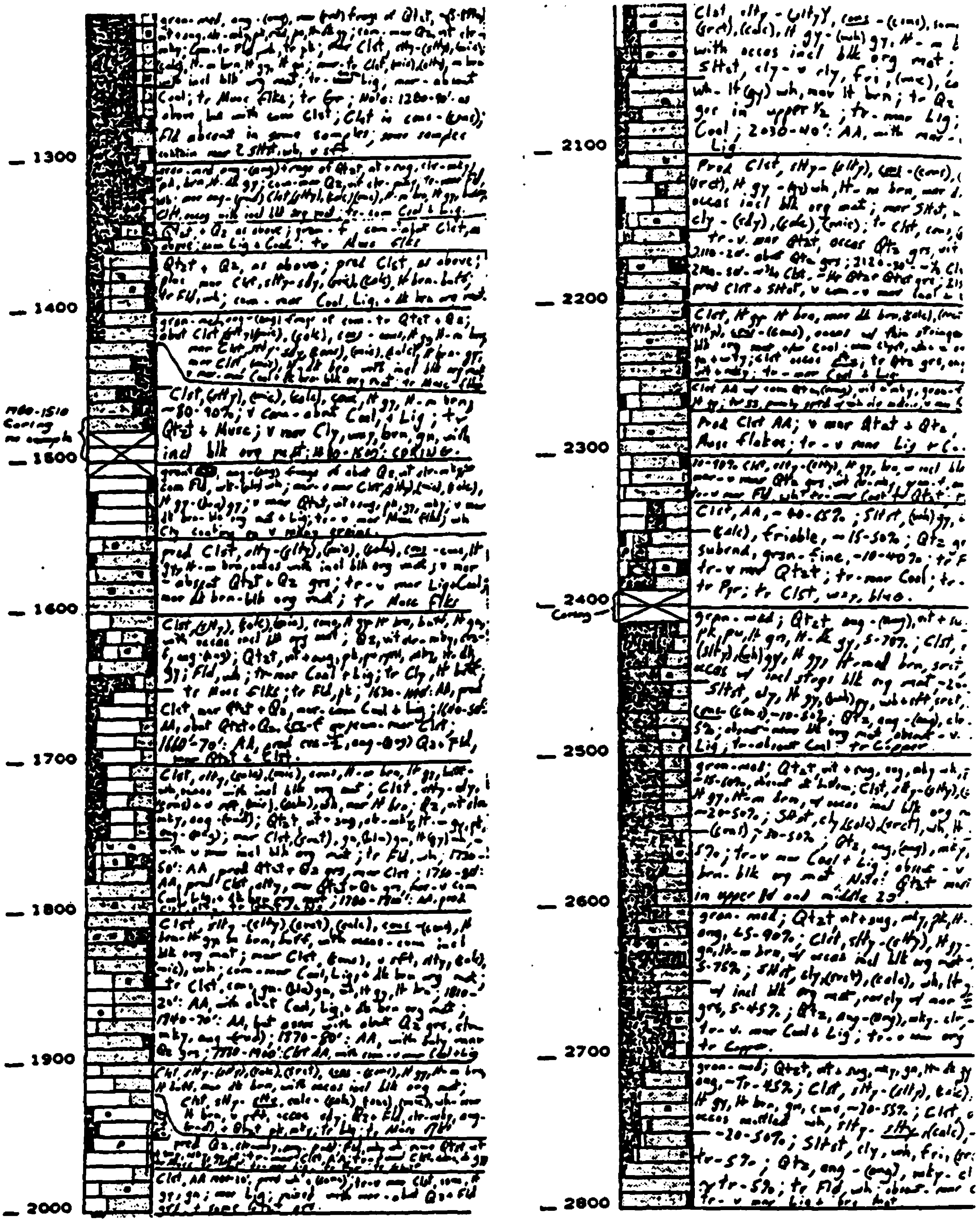
[illegible]

[illegible]

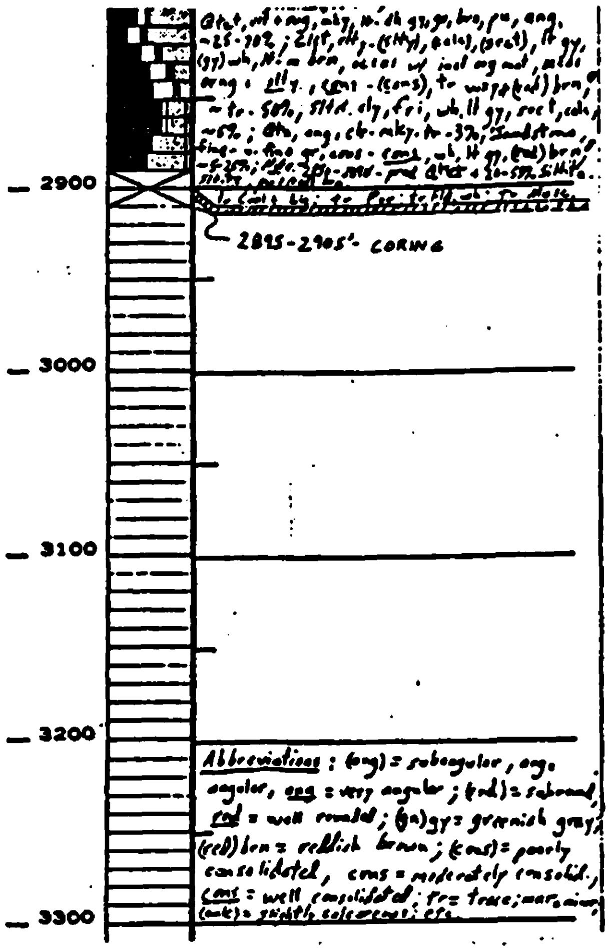
[illegible]

[illegible]

[illegible]



Lithologic log: Hole 4



Abbreviations: (ang) = subangular, ang = angular, ang = very angular; (rnd) = subround, rnd = well rounded; (gn)gy = greenish gray; (red) brn = reddish brown; (cons) = poorly consolidated, cons = moderately consolid., cons = well consolidated; tr = trace; mnr = minor; (calc) = slightly calcareous; etc.

Lithologic log: Hole 4